ESI-250DE

UNIVERSAL IMPEDANCE BRIDGE

INSTRUCTION MANUAL W/SCHEMATIC

esi

MODEL 250DE

UNIVERSAL IMPEDANCE BRIDGE

Instruction Manual

Part Number 13202 May 1985

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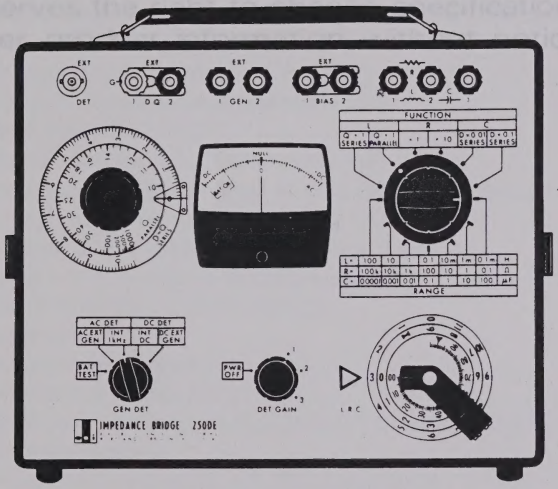

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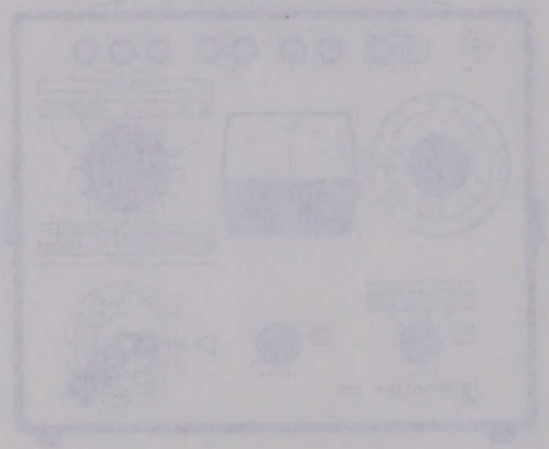

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ESI® Electro Scientific Industries, Inc.
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ESIPOT® Potentiometer
DEKABOX® Decade Resistors and Capacitors
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DEKADIAL® Decade Dials
DEKAMATIC® Automatic Unit
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DEKASTAT® Decode Rheostat
DEKAPACITOR® Decade Capacitor
DEKAVIDER® Decade Voltage Divider
KELVIN KLAMPS® Four-Terminal Clamps
KELVIN KLIPS® Four-Terminal Clips
PORTAMETRIC® Portable Measuring Instrument
PVB® Potentiometric Voltmeter Bridge

SECTION 1

INTRODUCTION

1.1 DESCRIPTION

The ESI® Model 250DE Impedance Bridge is an instrument that measures resistance, inductance, capacitance, and the dissipation factor (D) and the storage factor (Q) of inductors and capacitors.

The instrument is battery operated and completely portable. An internal generator supplies ac and dc, and an internal solid-state ac-dc detector indicates bridge balance.

Figure 1-1 is a simplified schematic diagram of the instrument in each of the four modes of operation: resistance, capacitance, and series and parallel inductance.

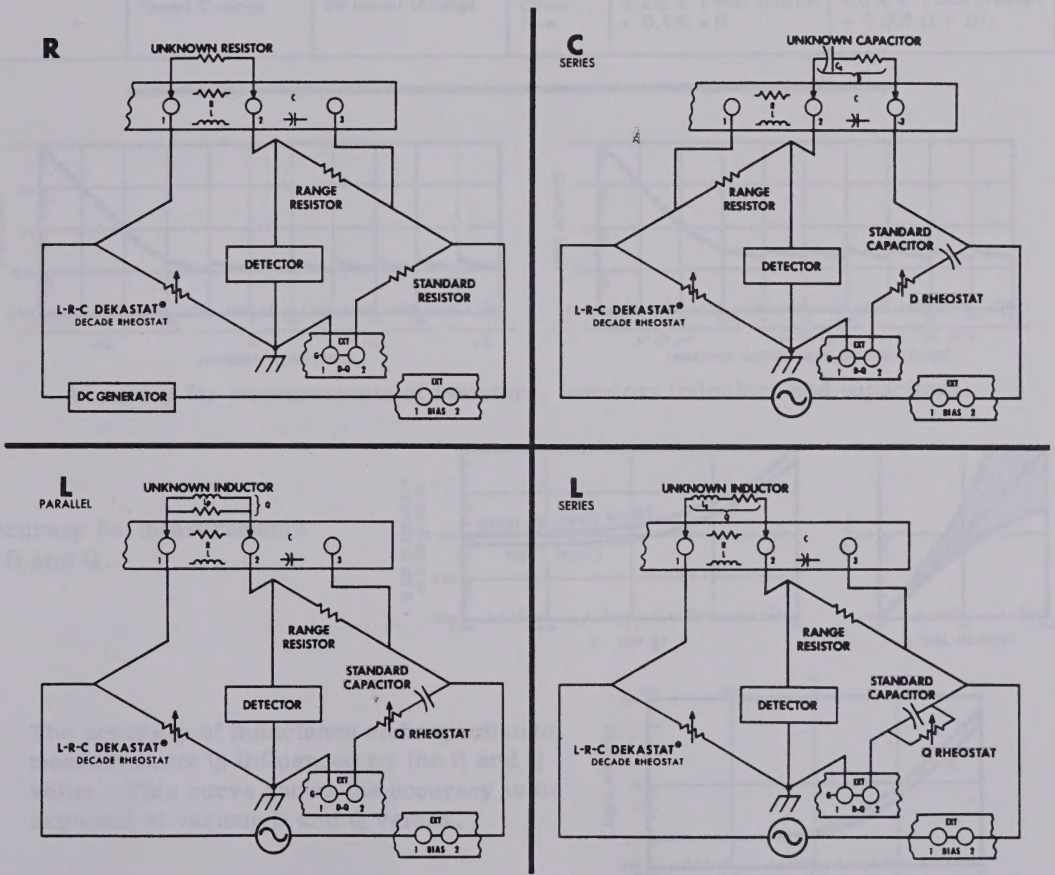


Figure 1-1. Simplified Schematic Diagrams

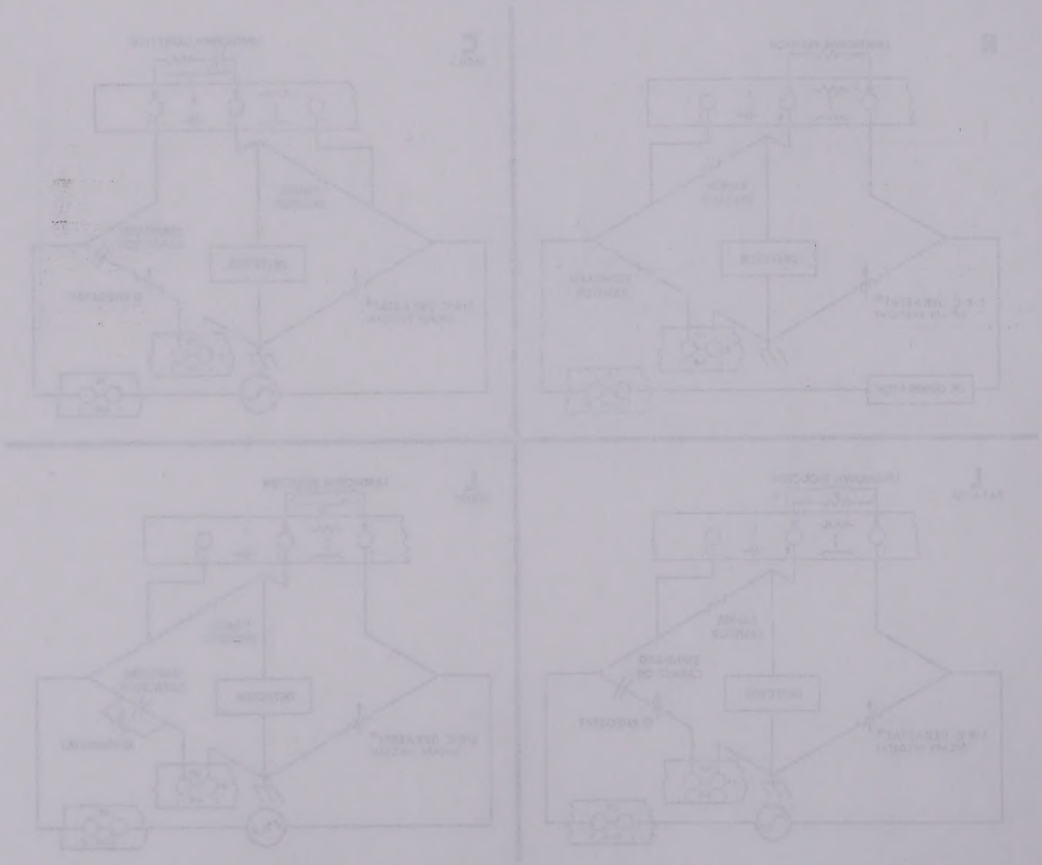
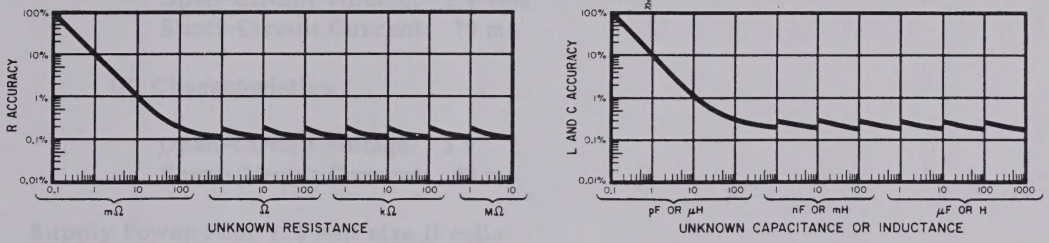


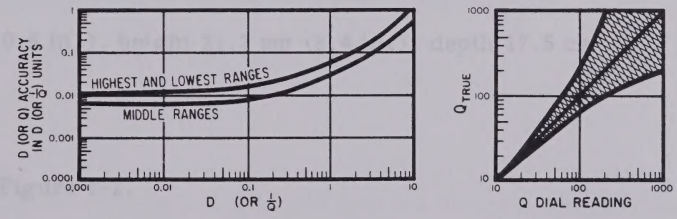
Table 1-1. Specified Accuracy of the Model 250DE Impedance Bridge

FUNCTION	RANGES		ACCURACY		
	MAGNITUDE	D OR Q	RANGE	MAGNITUDE	D OR 1/Q
RESISTANCE	0-12 MΩ in eight ranges; 0.1 mΩ per dial division on lowest R range		All eight ranges	0.1% + 1 dial division	
INDUCTANCE (Series and Parallel)	0-1200 H in seven ranges; 0.1 μH per dial division on lowest L range	SERIES Q = 0 to 10.5, 0.1 per dial division PARALLEL Q = 10 to 1000, scale reads Q; dial is linear in 1/Q	Highest and Lowest	0.2% + 1 dial division + 1.2%/Q	1.0% + 1 dial division + 0.012 $(1 + 1/Q^2)$
			Other Five	0.2% + 1 dial division + 0.7%/Q	1.0% + 1 dial division + 0.007 $(1 + 1/Q^2)$
CAPACITANCE (Series)	0-1200 μF in seven ranges; 0.1 pF per dial division on lowest C range	D = 0 to 1.05 in two ranges, 0.001 per dial division on lowest D range	Highest and Lowest	0.2% + 1 dial division + 1.0% x D	1.0% + 1 dial division + 0.01 $(1 + D^2)$
			Other Five	0.2% + 1 dial division + 0.5% x D	1.0% + 1 dial division + 0.005 $(1 + D^2)$



Accuracy for measurements of resistors, low-loss inductors and capacitors.

Accuracy for measurements of D and Q.



The accuracy of inductance and capacitance measurements is influenced by the D and Q value. This curve shows the accuracy to be expected at various D and Q values.

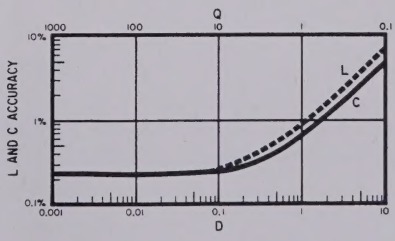
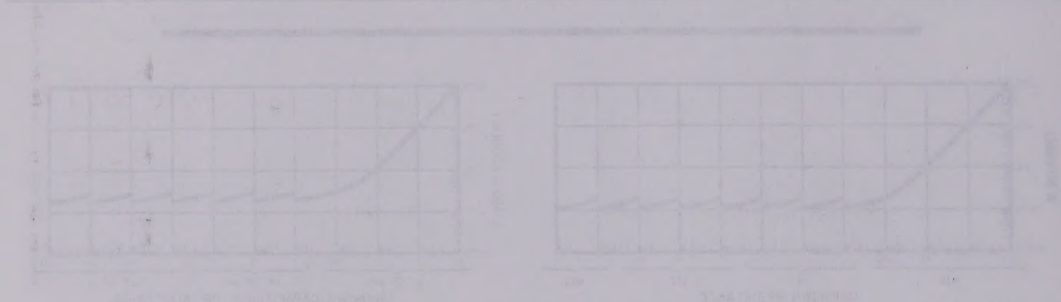


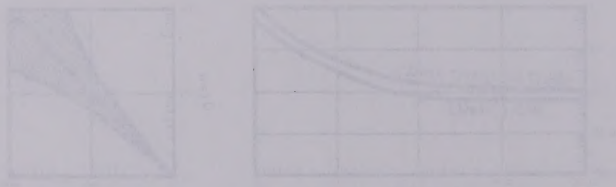
Figure 1-2. Accuracy Graphs

FUNCTION	RANGES		ACCURACY ±
	MAGNITUDE	D or Q	RANGE	MAGNITUDE	D or Q
RESISTANCE	0-1.2 MΩ in eight ranges 0.1 Ω to 1 MΩ full division on lowest R range		All eight ranges	0.1% × 1 dial division	
INDUCTANCE - Series and Parallel	0-1200 H in seven ranges 0.1 μH to 1 H full division on lowest L range	Z_{MIN} = 0.6 Ω at 1 kc; 2 Ω at 10 kc; 6 Ω at 30 kc; Z_{MAX} = 10 × 10⁶ Ω at 1 kc; 10 × 10⁶ Ω at 10 kc; 3 × 10⁶ Ω at 30 kc; D_{MIN} = 0.2 at 1 kc; 0.1 at 10 kc; 0.05 at 30 kc; D_{MAX} = 0.1 at 1 kc; 0.2 at 10 kc; 0.5 at 30 kc; Q_{MIN} = 5 at 1 kc; 10 at 10 kc; 20 at 30 kc; Q_{MAX} = 10 at 1 kc; 5 at 10 kc; 2 at 30 kc	Highest and lowest ranges	0.25% × 1 dial division + 1.25% Ω	1.0% × 1 dial division + 0.01 D + 1.0% Q
			Other ranges	0.25% × 1 dial division + 0.75% Ω	1.0% × 1 dial division + 0.005 D + 1.0% Q
CAPACITANCE - Series and Parallel	0-1200 μF in seven ranges 0.1 pF to 1 μF full division on lowest C range	D = 0.01 at 1 kc; 0.05 at 10 kc; 0.15 at 30 kc; D_{MAX} = 0.1 at 1 kc; 0.2 at 10 kc; 0.5 at 30 kc; Q_{MIN} = 10 at 1 kc; 2 at 10 kc; 0.7 at 30 kc	Highest and lowest ranges	0.25% × 1 dial division + 1.25% Ω	1.0% × 1 dial division + 0.01 D + 1.0% Q
			Other five ranges	0.25% × 1 dial division + 0.75% Ω	1.0% × 1 dial division + 0.005 D + 1.0% Q

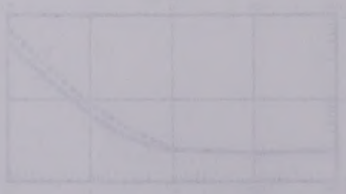
Table 1-1. Specified Accuracy of the Model 2305E Impedance Bridge



Accuracy for measurements of resistance, low-loss inductors and capacitors.



Accuracy for measurements of inductance and capacitance.



The accuracy of inductance and capacitance measurements is influenced by the D and Q value. This curve shows the accuracy to be expected at various D and Q values.

Figure 1-2. Accuracy Graphs

1.2 SPECIFICATIONS

Detector: A solid-state ac-dc amplifier null detector

AC Characteristics

Input Impedance: Approximately 1 MΩ
Sensitivity: Continuously variable, 10 μV minimum detectable signal
Frequency: 1 kHz

DC Characteristics

Input Resistance: Approximately 1 MΩ
Sensitivity: Continuously variable to 1 mV full scale, 20 μV minimum detectable signal

Generator: A solid-state ac generator with transformer output and diode rectifiers for dc

AC Characteristics

Open-Circuit Voltage: 2 V rms
Short-Circuit Current: 70 mA

DC Characteristics

Open-Circuit Voltage: 3 V
Short-Circuit Current: 40 mA

Supply Power Four 1.5 volt size D cells

Battery Life: Approximately 500 hours

Dimensions: Width 26.9 cm (10.6 in.), height 21.3 cm (8.4 in.), depth 17.5 cm (6.9 in.)

Weight: 5.4 kg (12 lb)

Accuracy: See Table 1-1 and Figure 1-2.

SECTION 2

OPERATION

The control and connections of the Model 250DE Impedance Bridge are shown in Figure 2-1.

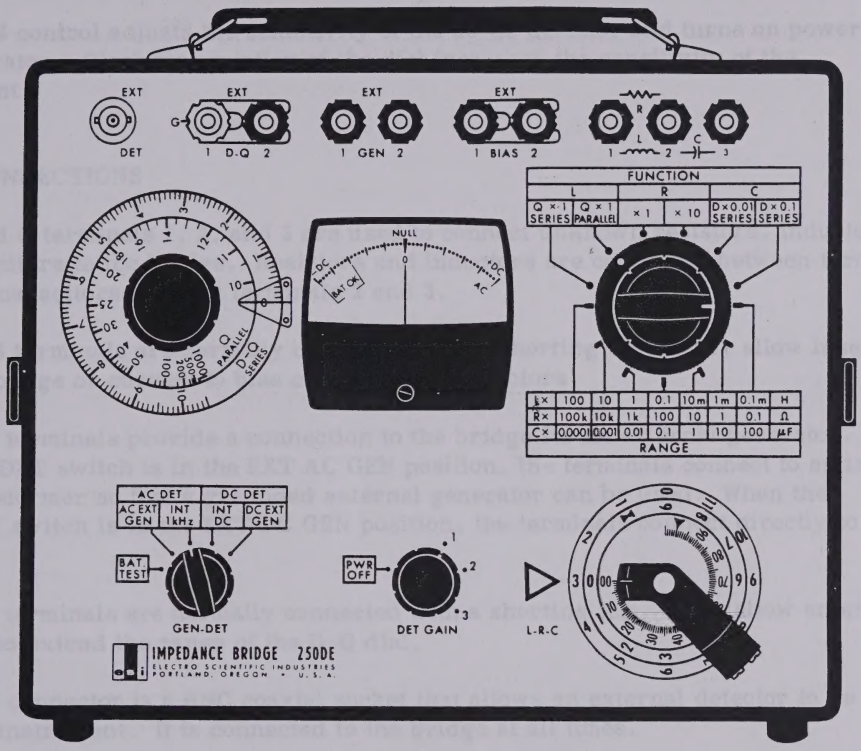


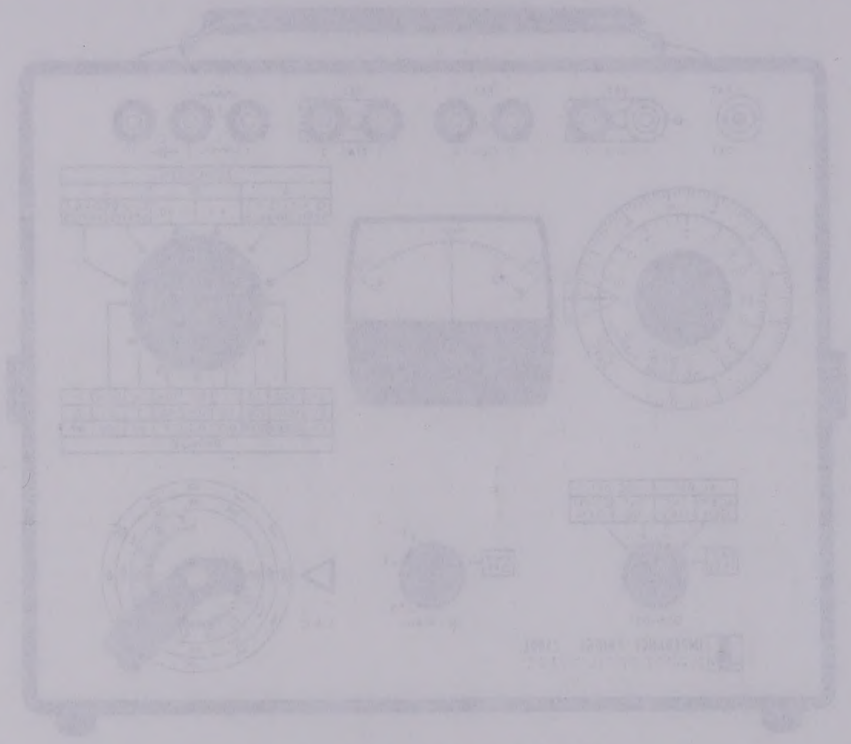
Figure 2-1. Model 250DE Panel View

2.1 CONTROLS

FUNCTION switch selects the type of bridge circuit to measure resistance, capacitance, or inductance.

RANGE switch selects the multiplier for each function.

L-R-C decade dials are a DEKASTAT® Decade Resistor that is the main balancing element of the bridge. The setting of the dials after the bridge is balanced indicates the value of the inductance, resistance, or capacitance.



D-Q dial is used to balance the phase of the capacitance or inductance bridge. The setting of the dial after the bridge is balanced indicates the value of dissipation factor (D) or storage factor (Q).

GEN-DET switch selects bridge generator and detector connections, ac or dc, internal or external generator. The switch also connects the internal batteries to the battery test circuit.

DET GAIN control adjusts the sensitivity of the ac-dc detector and turns on power to the generator. Clockwise rotation of the dial increases the sensitivity of the instrument.

2.2 CONNECTIONS

R, L, and C terminals 1, 2, and 3 are used to connect unknown resistors, inductors, and capacitors to the bridge. Resistors and inductors are connected between terminals 1 and 2, capacitors between terminals 2 and 3.

EXT BIAS terminals are normally connected with a shorting lug. They allow insertion of a dc voltage or current to bias capacitors or inductors.

EXT GEN terminals provide a connection to the bridge for an external generator. When the GEN-DET switch is in the EXT AC GEN position, the terminals connect to an isolation transformer so that a grounded external generator can be used. When the GEN-DET switch is in the EXT DC GEN position, the terminals connect directly to the bridge.

EXT D-Q terminals are normally connected with a shorting lug. They allow an external rheostat to extend the range of the D-Q dial.

EXT DET connector is a BNC coaxial socket that allows an external detector to be used with the instrument. It is connected to the bridge at all times.

2.3 BASIC OPERATION

Simple operating instructions are inside the instrument lid. Figure 2-2 is a reproduction of these instructions.

2.4 PRE-OPERATION CHECKS

Prior to making measurement with the Model 250DE, the batteries and meter pointer alignment should be checked. To check the batteries turn the DET GAIN control to 1 and set the GEN-DET switch to BAT. TEST. If the meter does not deflect beyond the BAT. OK mark, the batteries need replacement. The procedure for battery replacement is given in Figure 2-2.

To check the pointer alignment turn DET GAIN control as far counterclockwise as possible without turning the instrument off. Set the GEN-DET switch to DC EXT GEN. The pointer should be in the NULL position. If not, adjust the meter zeroing screw (on the meter at the base of the pointer) to obtain a null indication.

NOTE: If the pointer is more than one half meter division away from a null indication, the printed circuit contacts may be dirty. See Section 3.5.

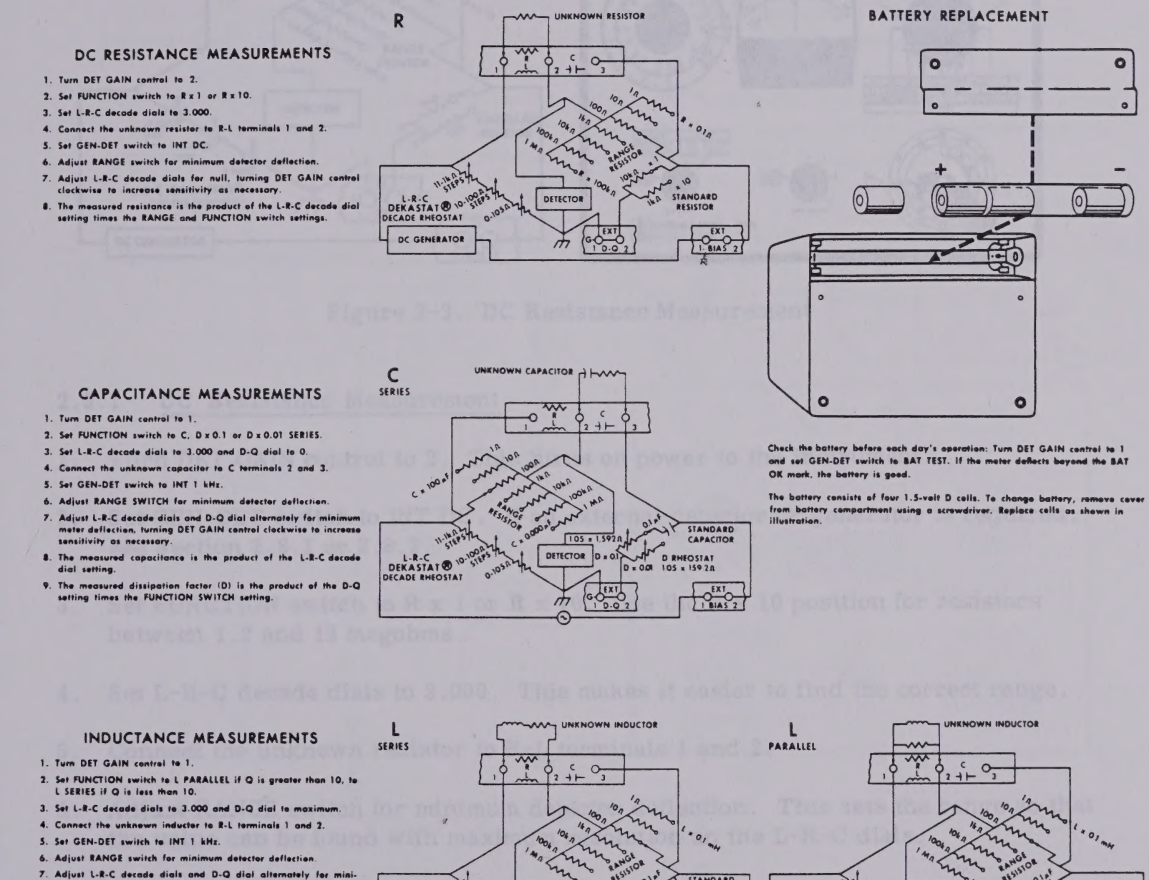
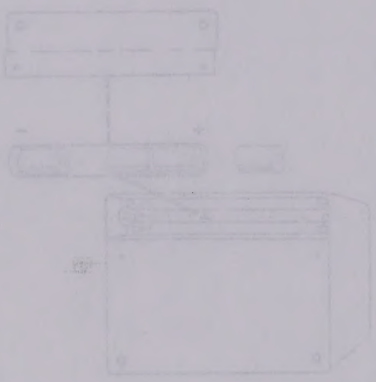

DC RESISTANCE MEASUREMENTS
1. Turn DET GAIN control to 2.
2. Set FUNCTION switch to R x 1 or R x 10.
3. Set L-R-C decade dials to 3.000.
4. Connect the unknown resistor to R-L terminals 1 and 2.
5. Set GEN-DET switch to INT DC.
6. Adjust RANGE switch for minimum detector deflection.
7. Adjust L-R-C decade dials for null, turning DET GAIN control clockwise to increase sensitivity as necessary.
8. The measured resistance is the product of the L-R-C decade dial setting times the RANGE and FUNCTION switch settings.
R
UNKNOWN RESISTOR
L-R-C DEKASTAT® DECADE RHEOSTAT
DETECTOR
STANDARD RESISTOR
DC GENERATOR
BATTERY REPLACEMENT
Check the battery before each day's operation: Turn DET GAIN control to 1 and set GEN-DET switch to BAT TEST. If the meter deflects beyond the BAT OK mark, the battery is good.
The battery consists of four 1.5-volt D cells. To change battery, remove cover from battery compartment using a screwdriver. Replace cells as shown in illustration.
CAPACITANCE MEASUREMENTS
1. Turn DET GAIN control to 1.
2. Set FUNCTION switch to C, D x 0.1 or D x 0.01 SERIES.
3. Set L-R-C decade dials to 3.000 and D-Q dial to 0.
4. Connect the unknown capacitor to C terminals 2 and 3.
5. Set GEN-DET switch to INT 1 kHz.
6. Adjust RANGE SWITCH for minimum detector deflection.
7. Adjust L-R-C decade dials and D-Q dial alternately for minimum meter deflection, turning DET GAIN control clockwise to increase sensitivity as necessary.
8. The measured capacitance is the product of the L-R-C decade dial setting.
9. The measured dissipation factor (D) is the product of the D-Q setting times the FUNCTION SWITCH setting.
C SERIES
UNKNOWN CAPACITOR
STANDARD CAPACITOR
D RHEOSTAT
INDUCTANCE MEASUREMENTS
1. Turn DET GAIN control to 1.
2. Set FUNCTION switch to L PARALLEL if Q is greater than 10, to L SERIES if Q is less than 10.
3. Set L-R-C decade dials to 3.000 and D-Q dial to maximum.
4. Connect the unknown inductor to R-L terminals 1 and 2.
5. Set GEN-DET switch to INT 1 kHz.
6. Adjust RANGE switch for minimum detector deflection.
7. Adjust L-R-C decade dials and D-Q dial alternately for minimum meter deflection, turning DET GAIN control clockwise to increase sensitivity as necessary.
8. The measured inductance is the product of the L-R-C decade dial setting times the RANGE switch setting.
9. The measured storage factor (Q) is read directly from the D-Q dial, inner scale for parallel and outer scale for series inductance.
L SERIES
UNKNOWN INDUCTOR
L PARALLEL
Q RHEOSTAT

Figure 2-2. Operating Instructions as they appear on instrument cover



2.5 RESISTANCE MEASUREMENT

Resistance is usually measured with direct current for maximum accuracy. The Mode 250DE Impedance Bridge can be used to measure resistance with alternating current, but external reactance compensation may be required.

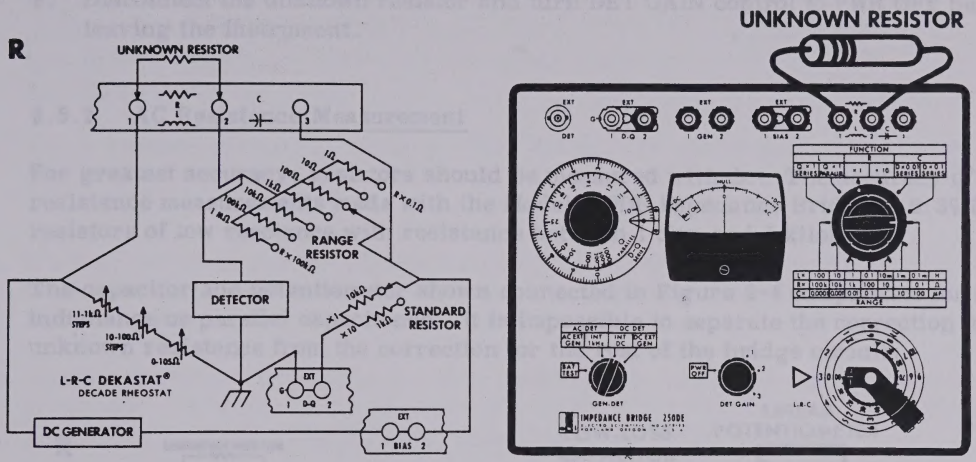


Figure 2-3. DC Resistance Measurement

2.5.1 DC Resistance Measurement

1. Turn DET GAIN control to 2. This turns on power to the instrument.

2. Set GEN-DET switch to INT DC. If an external detector or generator is required, see Section 2.8.1 or 2.8.2.

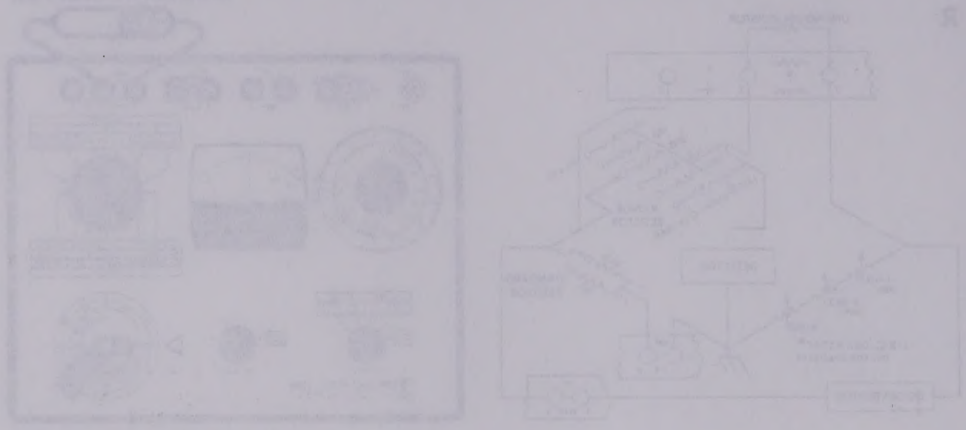
3. Set FUNCTION switch to R x 1 or R x 10. Use the R x 10 position for resistors between 1.2 and 12 megohms.

4. Set L-R-C decade dials to 3.000. This makes it easier to find the correct range.

5. Connect the unknown resistor to R-L terminals 1 and 2.

6. Adjust RANGE switch for minimum detector deflection. This sets the range so that the value can be found with maximum resolution on the L-R-C dials.

7. Adjust L-R-C decade dials for null. Each time the detector indication approaches zero, turn the DET GAIN control clockwise to increase sensitivity.



8. Read the measured resistance as the product of L-R-C dial setting times RANGE and FUNCTION switch settings. If L-R-C dial reading is less than 1.200, turn RANGE switch one step counterclockwise and repeat step 7 in order to take full advantage of the resolution.

9. Disconnect the unknown resistor and turn DET GAIN control to PWR OFF before leaving the instrument.

2.5.2 AC Resistance Measurement

For greatest accuracy, resistors should be measured with dc. The accuracy of ac resistance measurements made with the Model 250DE Impedance Bridge is 0.3% for resistors of low reactance with resistance between 1 ohm and 1 kilohm.

The capacitor and potentiometer shown connected in Figure 2-4 compensate for series inductance or parallel capacitance. It is impossible to separate the correction for the unknown resistance from the correction for the rest of the bridge circuit.

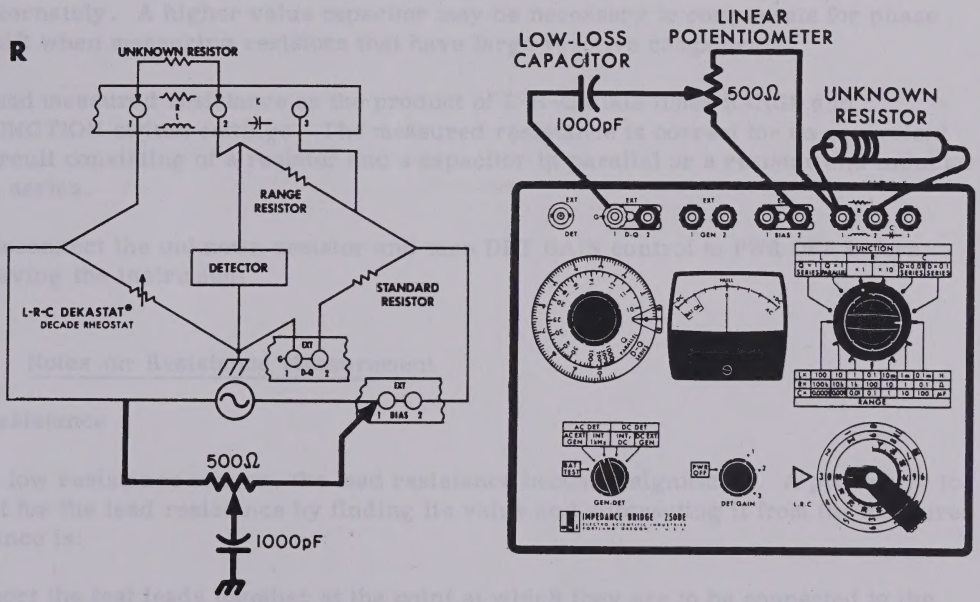
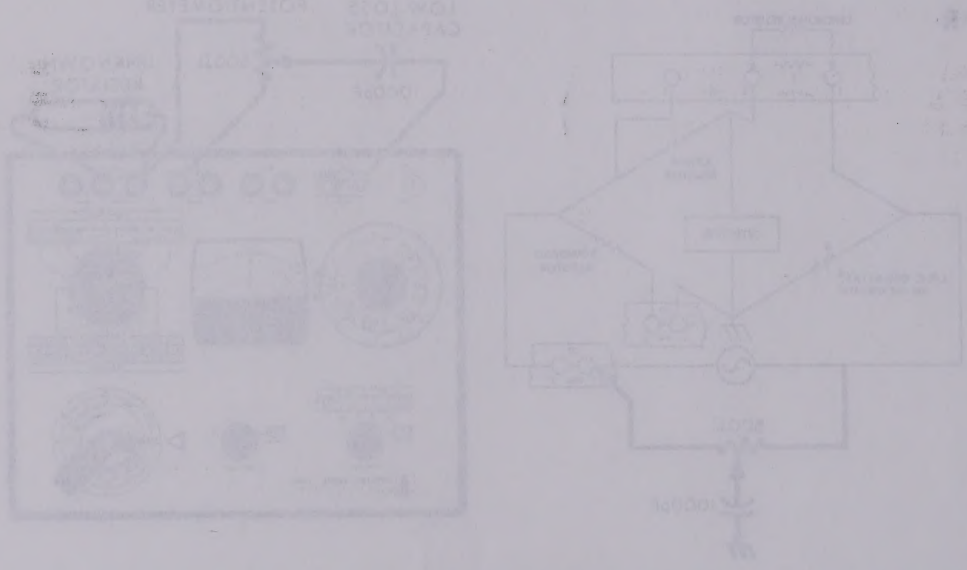


Figure 2-4. AC Resistance Measurement

1. Turn DET GAIN control to 1. This turns on power to the instrument.

2. Set FUNCTION switch to R x 1 or R x 10. Use the R x 10 position for resistors between 1.2 and 12 megohms.

3. Set L-R-C decade dials to 3.000. This makes it easier to find the correct range.



4. Connect the unknown resistor to R-L terminals 1 and 2. Make good contact with the terminals.

5. Set GEN-DET switch to INT 1 kHz. If an external ac detector or generator is required, see Section 2.8.1 or 2.8.3.

6. Adjust RANGE switch for minimum detector deflection. Turn DET GAIN control clockwise to increase sensitivity if necessary. If no range gives noticeably less deflection than any other, try measuring resistance on dc for a first approximation of the range.

7. Try to balance bridge by adjusting L-R-C dials. The null indication on the meter may not be very sharp, which indicates that there is an uncompensated phase shift.

8. If a null cannot be reached, connect potentiometer and capacitor to the terminals as shown in Figure 2-4. Be sure to use a low-loss capacitor; air and polystyrene dielectrics are sufficient.

9. Balance the bridge by adjusting L-R-C decade dials and external potentiometer alternately. A higher value capacitor may be necessary to compensate for phase shift when measuring resistors that have large reactive components.

10. Read measured resistance as the product of L-R-C dials times RANGE and FUNCTION switch settings. The measured resistance is correct for an equivalent circuit consisting of a resistor and a capacitor in parallel or a resistor and inductor in series.

11. Disconnect the unknown resistor and turn DET GAIN control to PWR OFF before leaving the instrument.

2.5.3 Notes on Resistance Measurement

Low Resistance

On the low resistance ranges, the lead resistance becomes significant. A procedure to correct for the lead resistance by finding its value and subtracting it from the measured resistance is:

1. Short the test leads together at the point at which they are to be connected to the unknown resistor.

2. Measure the resistance of the leads. There is no loss of accuracy if the resistance of the leads is measured on the same range that the unknown resistor will be measured on.

3. Connect the leads to the unknown resistor and measure the resistance.

4. Subtract the lead resistance (step 2) from the measured resistance (step 3).

High Resistance

On the high resistance ranges, take care to avoid leakage across a resistor under test. Insulation with a resistance of 10^9 ohms, which is adequate for most purposes, will cause a measurement error of 1% if it shunts a 10-mehohm resistor.

2.6 CAPACITANCE MEASUREMENT

The Model 250DE Impedance Bridge measures capacitance in terms of a two-element equivalent circuit consisting of a capacitor in series with a resistor. The internal ac generator and detector of the Model 250DE bridge are tuned to 1 kilohertz. Other frequencies can be used but an external generator and detector are required. (See Section 2.8.4.)

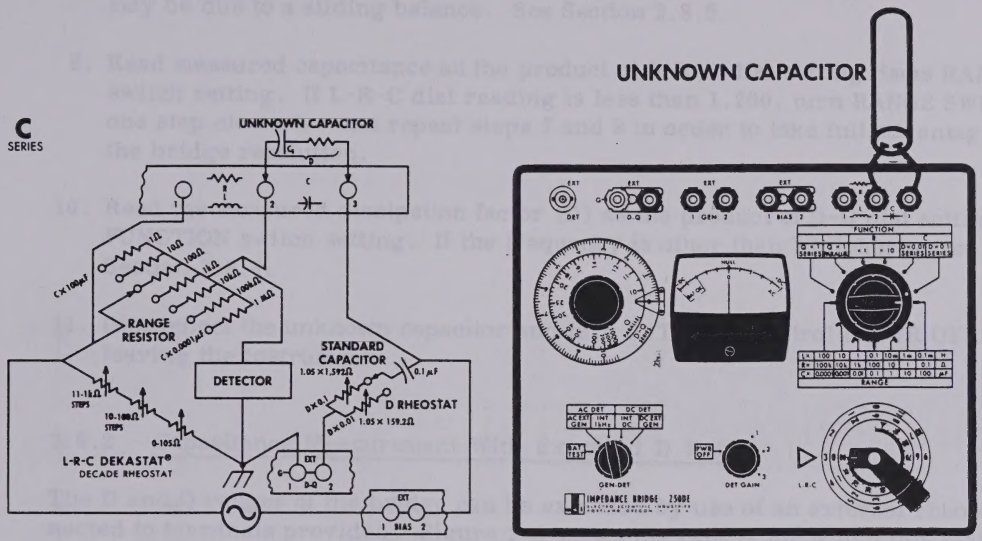


Figure 2-5. Capacitance Measurement

2.6.1 Normal Capacitance Measurement

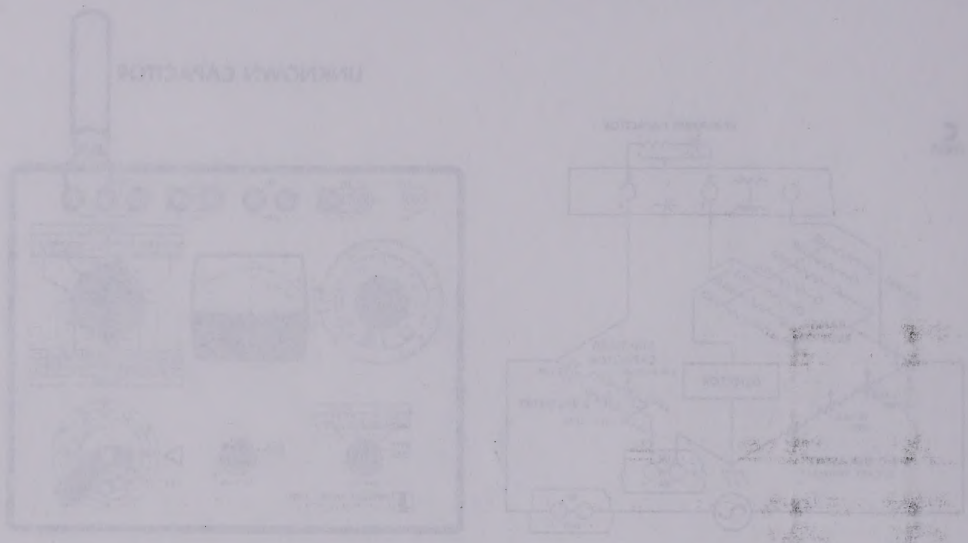
1. Turn DET GAIN control to 1. This turns on power to the instrument.

2. Set FUNCTION switch to C, D x 0.1 SERIES. This is the preferred D range for a preliminary balance.

3. Set L-R-C decade dials to 3.000 and D-Q dial to 0. These settings make it easier to find the correct C range.

4. Connect the unknown capacitor to C terminals 2 and 3. Make good contact with the terminals.

5. Set GEN-DET switch to INT 1 kHz. If an external ac detector or generator is required, see Section 2.8.1 or 2.8.3.



6. Adjust RANGE switch for minimum detector deflection. Turn DET GAIN control clockwise to increase the sensitivity if necessary.

7. Adjust L-R-C decade dials and D-Q dial alternately for minimum meter deflection. As the null is approached, turn the DET GAIN control clockwise to increase sensitivity.

8. If D-Q dial setting is less than 1, set FUNCTION switch to D x 0.01. If there is some difficulty in balancing the bridge, especially if the D is greater than 1, it may be due to a sliding balance. See Section 2.8.5.

9. Read measured capacitance as the product of L-R-C dial setting times RANGE switch setting. If L-R-C dial reading is less than 1.200, turn RANGE SWITCH one step clockwise and repeat steps 7 and 8 in order to take full advantage of the bridge resolution.

10. Read the measured dissipation factor (D) as the product of D-Q dial setting times FUNCTION switch setting. If the frequency is other than 1 kilohertz, see Section 2.8.4.

11. Disconnect the unknown capacitor and turn DET GAIN control to PWR OFF before leaving the instrument.

2.6.2 Capacitance Measurement With Extended D Range

The D and Q ranges of the bridge can be extended by use of an external rheostat connected to terminals provided. Figure 2-6 shows the ranges for which this technique is advisable.

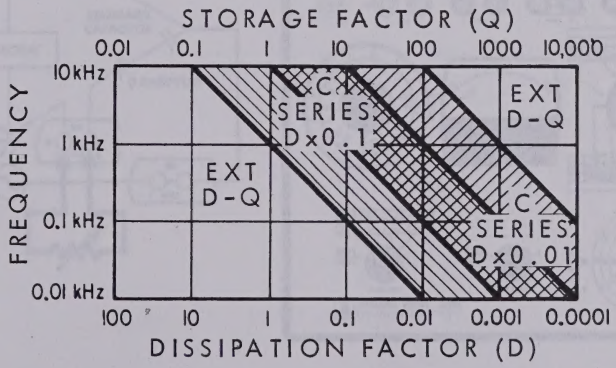
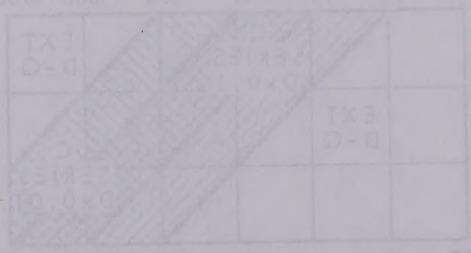


Figure 2-6. D and Q Ranges

1. Remove shorting lug from between EXT D-Q binding posts. This lug may be pivoted to one side.


EXT
D-Q
EXT
D-Q

2. Connect an external rheostat between EXT D-Q binding posts. See Figure 2-7.

3. Balance the bridge using external rheostat and D-Q dial. The measured capacitance is the product of the L-R-C dial setting times the setting of the RANGE switch.

4. Calculate D:

$$D = f_k \ (0.628 \ R_k + D_{dial})$$

where: D is the dissipation factor.

f_k is the frequency in kilohertz.

R_k is the resistance of the external D rheostat in kilohms.

D_{dial} is the D-Q dial reading.

$f_k = 1$ if the internal generator and detector are used.

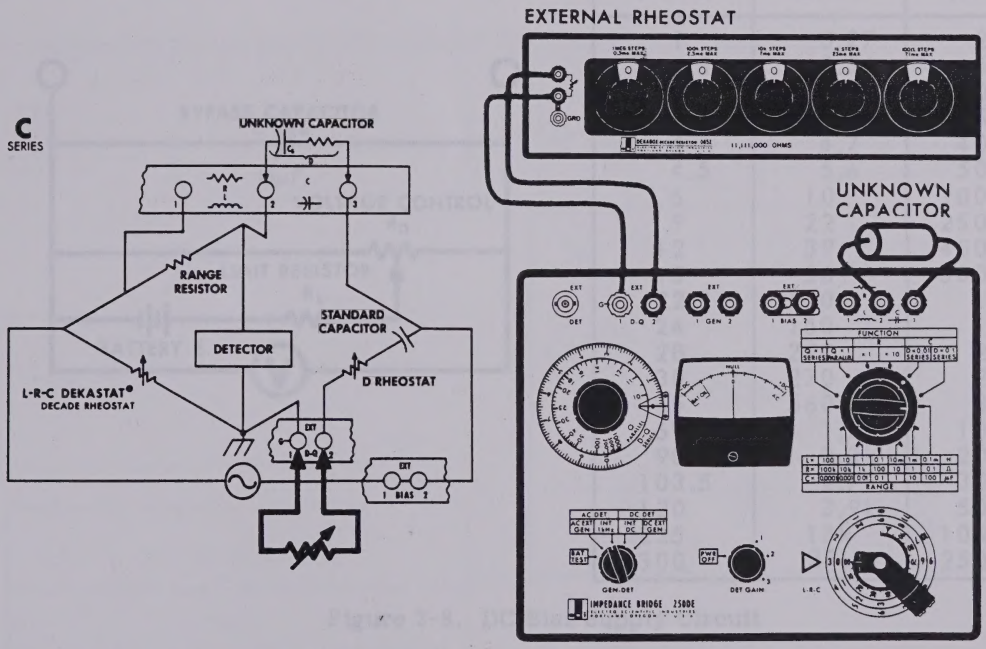
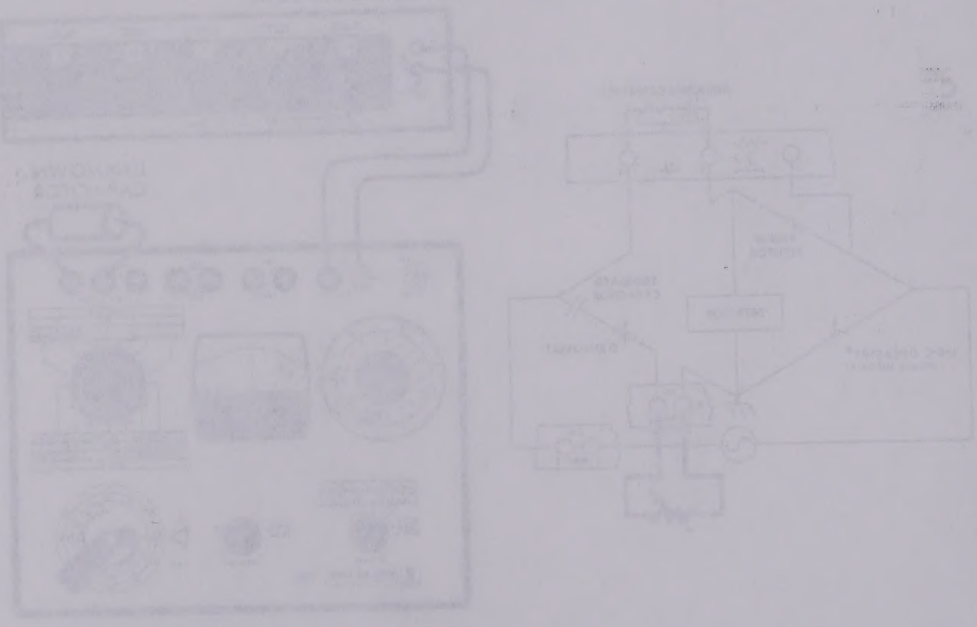


Figure 2-7. External D Rheostat

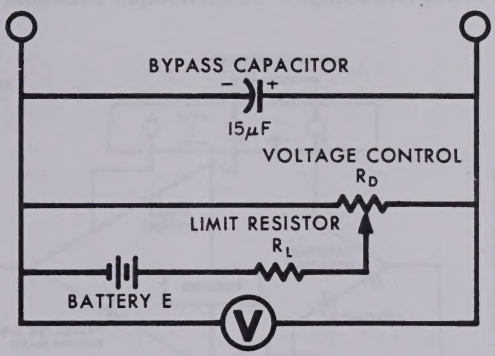


2.6.3 Capacitance Measurement Using DC Bias

Some capacitors need a polarizing voltage. Electrolytic and tantalum capacitors, for example, may give erroneous readings unless they are biased to prevent polarity reversal during test. Many electrolytic and tantalum capacitors can be damaged by the reverse half-cycle of an alternating current, although not generally by a voltage level as low as that used in the Model 250DE Impedance Bridge.

DC Bias Supply

The dc bias should be supplied from a power-limited source in order to prevent damage to the bridge in case the unknown capacitor terminals are shorted. The dc supply circuit is shown in Figure 2-8.

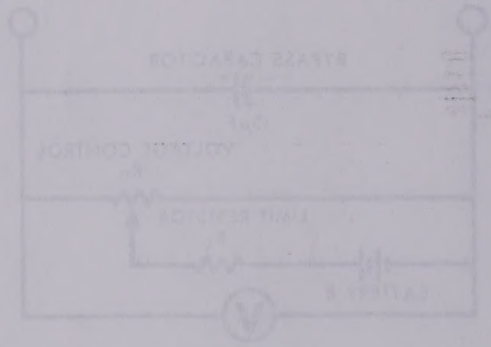


SUPPLY VOLTAGE E (VOLTS)	LIMITING RESISTOR R_L (OHMS)	VOLTAGE CONTROL R_D (OHMS)
1	0.27	2
1.5	0.56	5
2	1.0	10
3	2.7	25
4	4.7	40
4.5	5.6	50
6	10	100
9	22	250
12	39	400
15	56	500
22.5	150	1.5k
24	150	1.5k
28	220	2.5k
30	270	2.5k
45	560	3.0k
67.5	1.2k	10k
90	2.2k	20k
103.5	2.7k	30k
120	3.9k	50k
225	13k	100k
300	27k	250k

Figure 2-8. DC Bias Supply Circuit

The power in the circuit shown is limited to 1 watt by resistor R_L. Values shown are for commonly available voltages. The limiting resistors can have tolerances of 20% and should be rated at 5 watts or more. If the proper value of resistance is not available, use a larger value rather than smaller. The voltage control potentiometer may differ from the listed value by a factor of 2. It should be rated at 1 watt or more.

SUPPLY VOLTAGE E (VOLTS)	LIMITING RESISTOR R_L (OHMS)	VOLTAGE CONTROL R_C (OHMS)
1	0.27	2
1.5	0.24	5
2	1.0	10
3	2.7	25
4	4.7	50
4.5	7.5	75
5	10	100
6	22	250
12	75	500
15	56	500
22.5	150	1.5K
24	130	1.5K
28	220	2.2K
30	270	2.5K
45	560	3.0K
67.5	1.2K	10K
90	2.2K	20K
103.5	2.7K	30K
120	3.9K	50K
225	13K	100K
300	27K	250K



If a supply voltage much different from those listed is to be used, use the following formula to determine the proper value of limiting resistance:

$$R_L = \frac{E^2}{4}$$

Batteries are recommended because most line-operated power supplies have high leakage capacitance to ground and many have objectionably high dc leakage to ground.

For protection of the standard capacitor, do not use a voltage higher than 500 volts.

Operating Procedure

1. Set FUNCTION switch to C. With this setting, the standard capacitor and the unknown capacitor will block dc current from the other bridge arms.

2. Connect the unknown capacitor to C terminals 2 and 3. See Figure 2-9.

3. Remove shorting lug and connect dc bias supply between EXT BIAS terminals 1 and 2. See Figure 2-9. The shorting lug can be pivoted to one side.

4. Adjust dc voltage as required.

5. Measure capacitance. See Section 2.6.1 for the normal procedure.

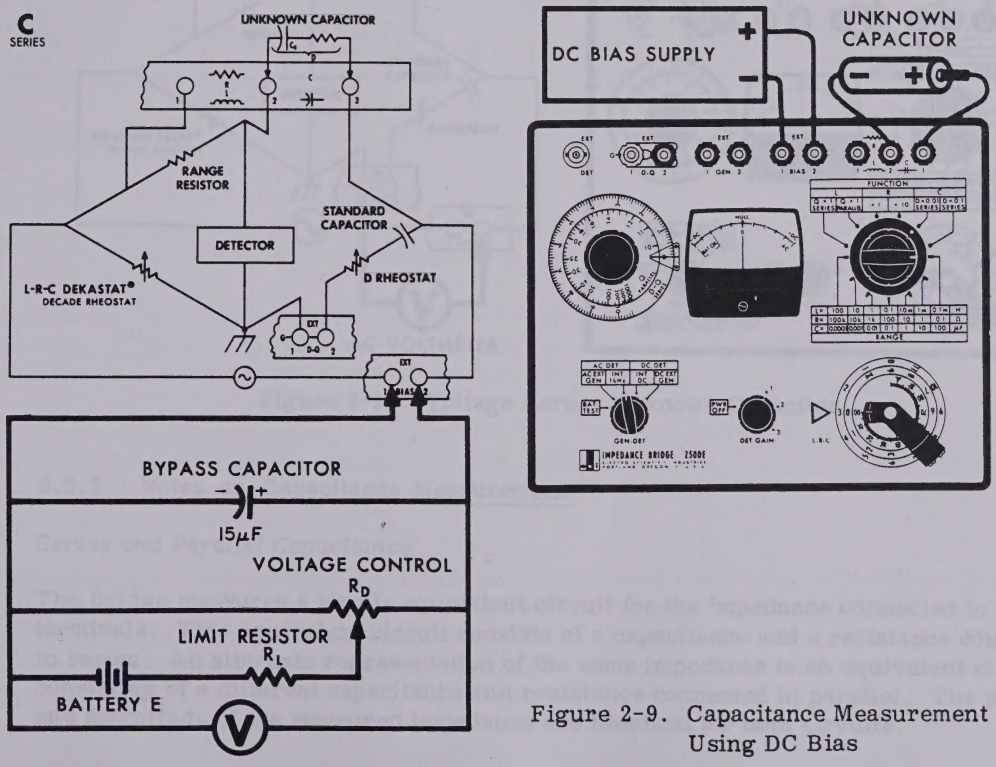
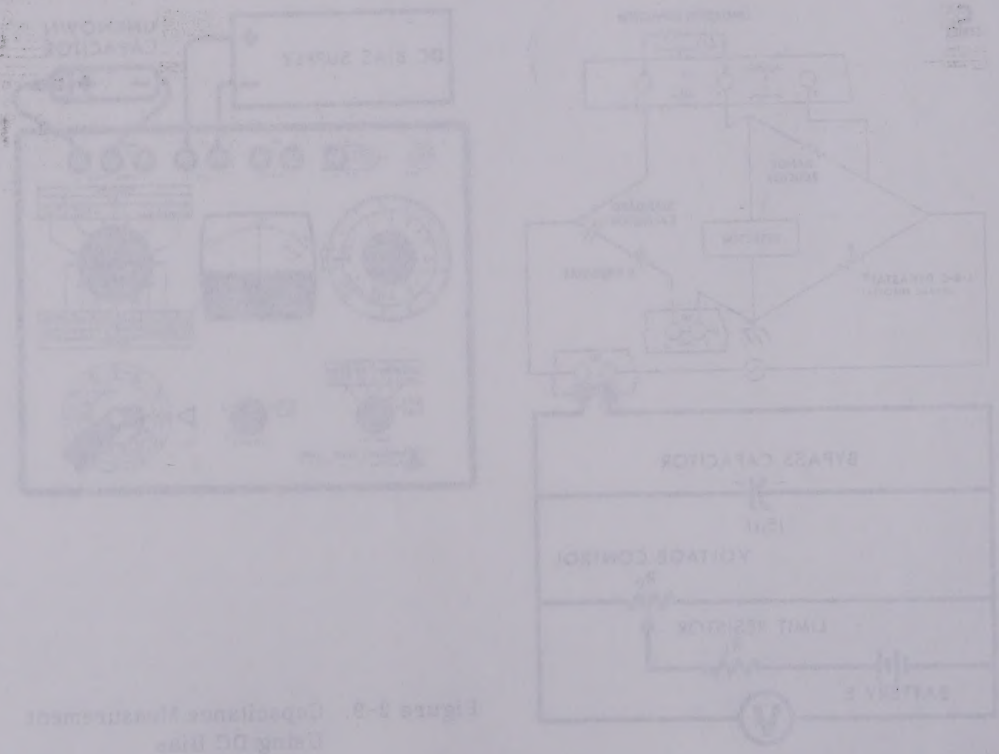


Figure 2-9. Capacitance Measurement Using DC Bias



2.6.4 Voltage Across Unknown Capacitor

In many cases it is necessary to measure the ac voltage across a capacitor being tested. With the following procedure, the voltage can be measured with a high-impedance ac voltmeter without loading the capacitor under test.

1. Connect grounded terminal of ac voltmeter to EXT D-Q terminal 1 and other terminal of the voltmeter to EXT BIAS terminal 2 (see Figure 2-10).

2. Balance the bridge and then read voltage on the voltmeter.

Since measuring voltage this way does not load the capacitor under test, the voltage will be correct. The capacitance reading of the bridge may be incorrect while the voltmeter is connected because the voltmeter may load the standard capacitor. For the correct capacitance reading, disconnect the voltmeter from the EXT BIAS terminal and rebalance the bridge.

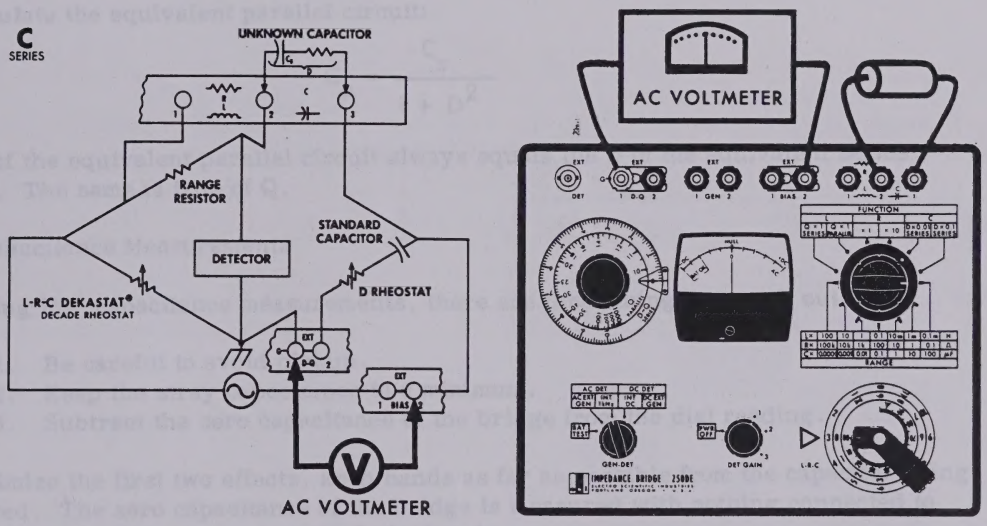
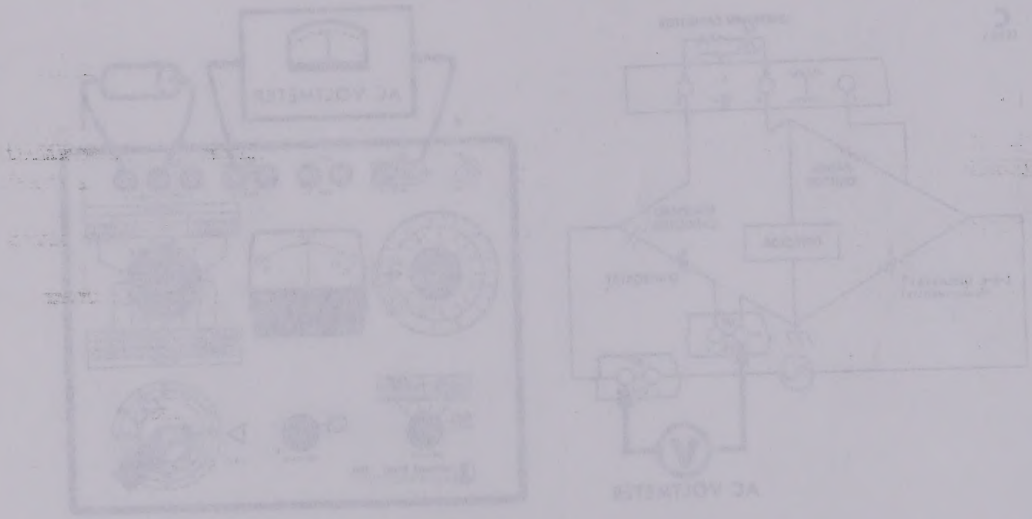


Figure 2-10. Voltage Across Unknown Capacitor

2.6.5 Notes on Capacitance Measurement

Series and Parallel Capacitance

The bridge measures a simple equivalent circuit for the impedance connected to its terminals. This equivalent circuit consists of a capacitance and a resistance connected in series. An alternate representation of the same impedance is an equivalent circuit consisting of a different capacitance and resistance connected in parallel. The phase and magnitude of the measured impedance are identical for both circuits.


AC VOLTMETER

When the bridge measures series capacitance, C_S:

C_S = (RANGE switch setting) x (L-R-C decade dial reading)
D = (FUNCTION switch setting) x (D-Q dial reading) x (f_{kHz})

$$Q = \frac{1}{D}$$

$$R_s = \frac{D}{2\pi f C_s}$$

$$Z = \frac{D - j}{2\pi f C_s}$$

R_s in kilohms
f in kilohertz
C_s in microfarads
$j = \sqrt{-1}$
Z in kilohms

To calculate the equivalent parallel circuit:

$$C_p = \frac{C_s}{1 + D^2}$$

The D of the equivalent parallel circuit always equals the D of the equivalent series circuit. The same is true of Q.

Low-Capacitance Measurements

In making low-capacitance measurements, there are three things to watch out for:

1. Be careful to avoid pickup.
2. Keep the stray capacitance to a minimum.
3. Subtract the zero capacitance of the bridge from the dial reading.

To minimize the first two effects, keep hands as far as possible from the capacitor being measured. The zero capacitance of the bridge is measured with nothing connected to the C terminals; it is approximately 2 picofarads.

Keep the leads as short and direct as possible. If extended leads are necessary, the lead from terminal 2 should be shielded (see Section 2.8.6).

High-Capacitance Measurements

The bridge measures the total impedance connected to its terminals. Both the unknown capacitor and its leads contribute to this impedance. The leads have some resistance and inductance which affect the value read from the bridge. For the greatest accuracy, minimize the lead impedance. Short heavy leads will reduce the resistance and closely spaced, twisted leads will reduce inductance and the pickup of stray fields.

2.7 INDUCTANCE MEASUREMENT

The Model 250DE Impedance Bridge measures inductance in terms of a two-element equivalent circuit consisting of an inductance either in series or in parallel with a resistance. The internal ac generator and detector of the Model 250DE Bridge are tuned to 1 kilohertz. Other frequencies can be used, but an external generator and detector are required. (See Section 2.8.4.)

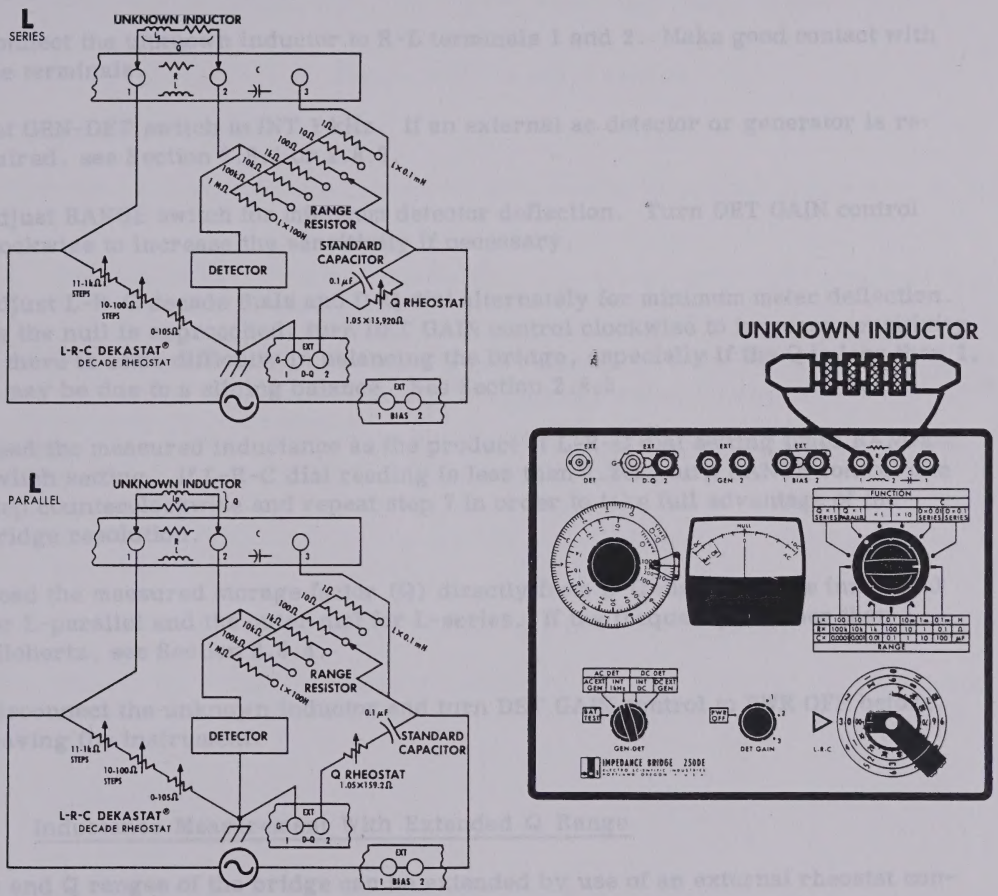
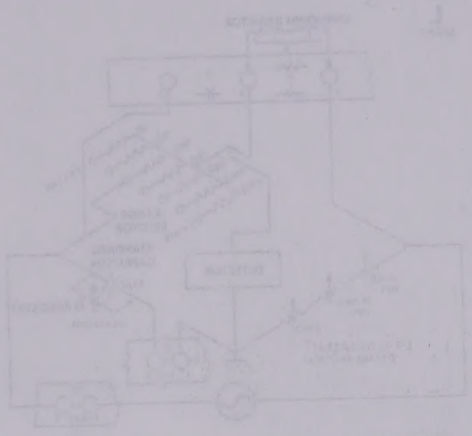
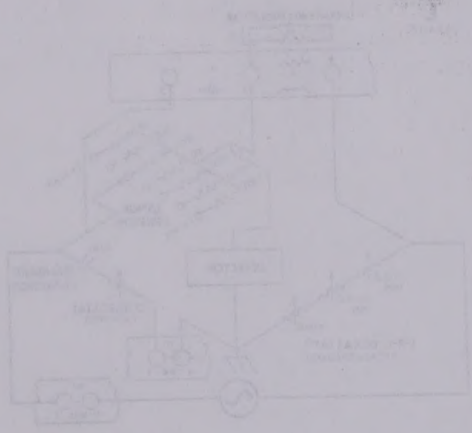


Figure 2-11. Inductance Measurement





2.7.1 Normal Inductance Measurements

1. Turn DET GAIN control to 1. This turns on power to the instrument.

2. Set FUNCTION switch to L, either Q x 1 SERIES or Q x 1 PARALLEL. Use the SERIES position for Q less than 10, the PARALLEL position for Q greater than 10.

3. Set L-R-C decade dials to 3.000 and D-Q dial to 1000 or 10.5. These settings make it easier to find the correct range.

4. Connect the unknown inductor to R-L terminals 1 and 2. Make good contact with the terminals.

5. Set GEN-DET switch to INT 1 kHz. If an external ac detector or generator is required, see Section 2.8.1 or 2.8.3.

6. Adjust RANGE switch for minimum detector deflection. Turn DET GAIN control clockwise to increase the sensitivity if necessary.

7. Adjust L-R-C decade dials and D-Q dial alternately for minimum meter deflection. As the null is approached, turn DET GAIN control clockwise to increase sensitivity. If there is some difficulty in balancing the bridge, especially if the Q is less than 1, it may be due to a sliding balance. See Section 2.8.5.

8. Read the measured inductance as the product of L-R-C dial setting times RANGE switch setting. If L-R-C dial reading is less than 1.200, turn RANGE control one step counterclockwise and repeat step 7 in order to take full advantage of the bridge resolution.

9. Read the measured storage factor (Q) directly from D-Q dial. Use the inner dial for L-parallel and the outer dial for L-series. If the frequency is other than 1 kilohertz, see Section 2.8.4.

10. Disconnect the unknown inductor and turn DET GAIN control to PWR OFF before leaving the instrument.

2.7.2 Inductance Measurement With Extended Q Range

The D and Q ranges of the bridge can be extended by use of an external rheostat connected to terminals provided. Figure 2-12 shows the range for which this technique is advisable.

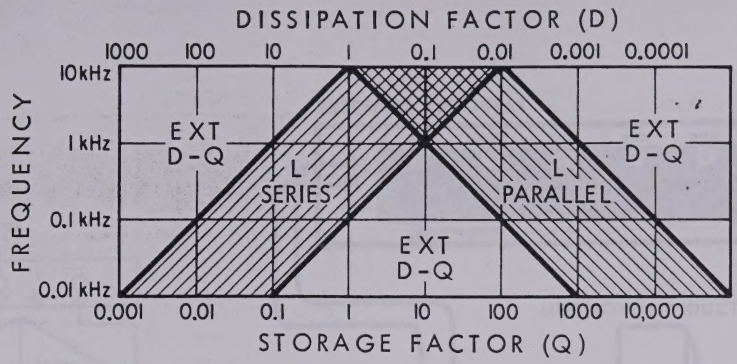


Figure 2-12. D and Q Ranges

Preliminary Procedure

The external Q rheostat can be used for either series or parallel inductance. In either case:

1. Set FUNCTION switch to L-PARALLEL. This bridge circuit gives the best result for either series or parallel inductance.

2. Turn D-Q dial to 1000 and leave it there during the measurement. This shorts out the internal D-Q rheostat, which is a tapped rheostat. To go beyond 1000 will increase the resistance.

Parallel Inductance

1. Remove shorting lug from between EXT D-Q binding posts. The lug may be pivoted to one side.

2. Connect an external rheostat between EXT D-Q binding posts. See Figure 2-13.

3. Balance the bridge using external rheostat instead of D-Q dial. The measured inductance is the product of the L-R-C dial setting times the setting of the RANGE control.

4. Calculate: Q:

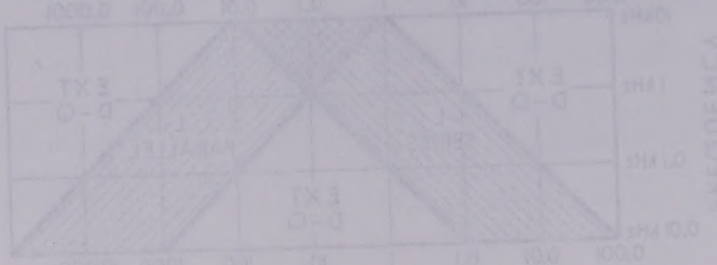
$$Q = \frac{1.592}{f_k R_k}$$

Q is the storage factor.

f_k is the frequency in kilohertz.

R_k is the resistance in kilohms of the external Q rheostat.

f_k = 1 if the internal generator and detector are used.



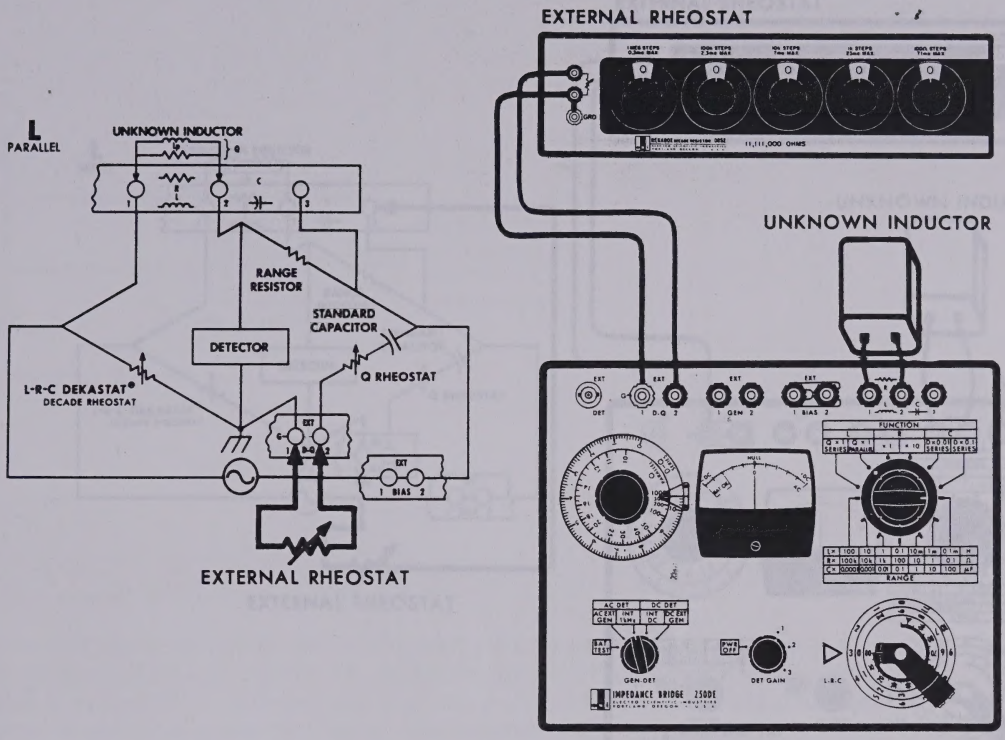


Figure 2-13. Parallel Inductance, External Q Rheostat

Series Inductance

1. Connect an external rheostat between C terminal 3 and EXT D-Q terminal 1. Be sure that the shorting lug is connected between EXT D-Q terminals. See Figure 2-14.

2. Balance the bridge using external rheostat instead of D-Q dial. The measured inductance is the product of the L-R-C dial times the setting of the RANGE switch.

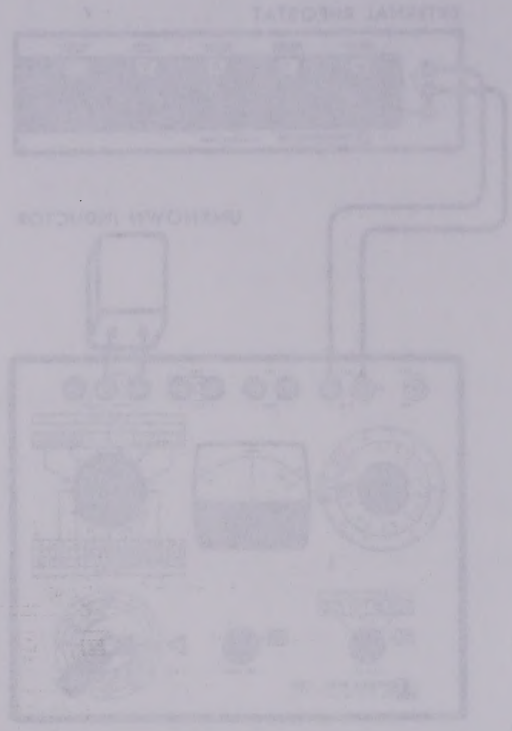
3. Calculate Q:

$$Q = 0.628 f_k R_k$$

Q is the storage factor.

f_k is the frequency in kilohertz.

R_k is the resistance in kilohms of the external Q rheostat.



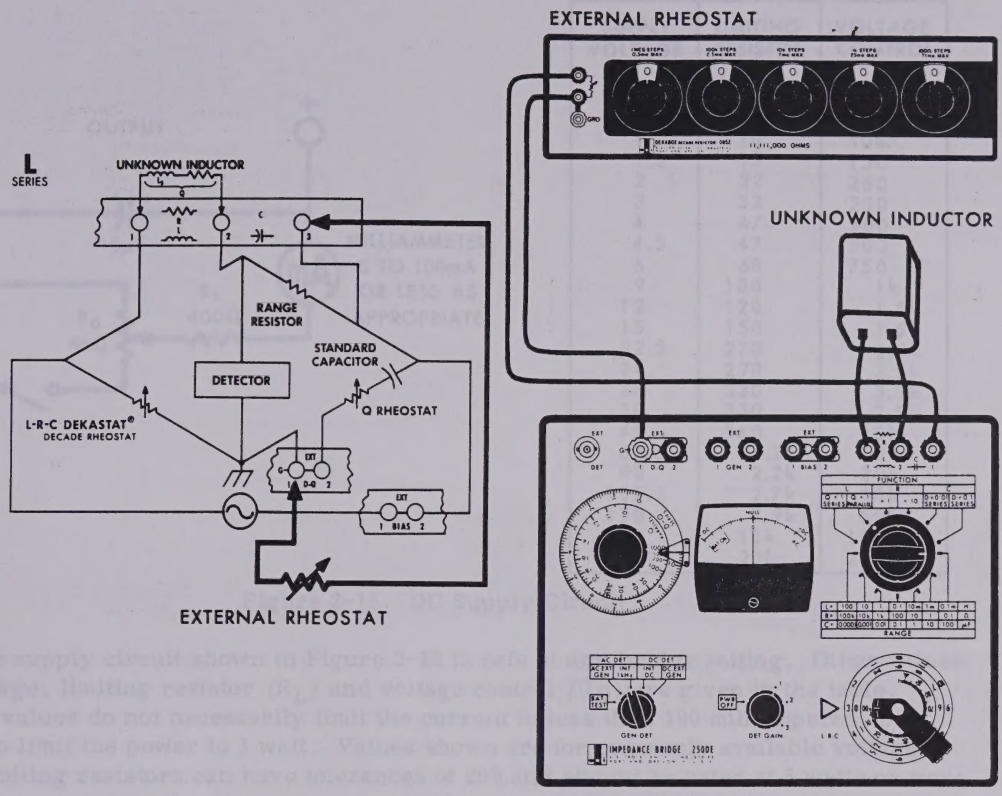


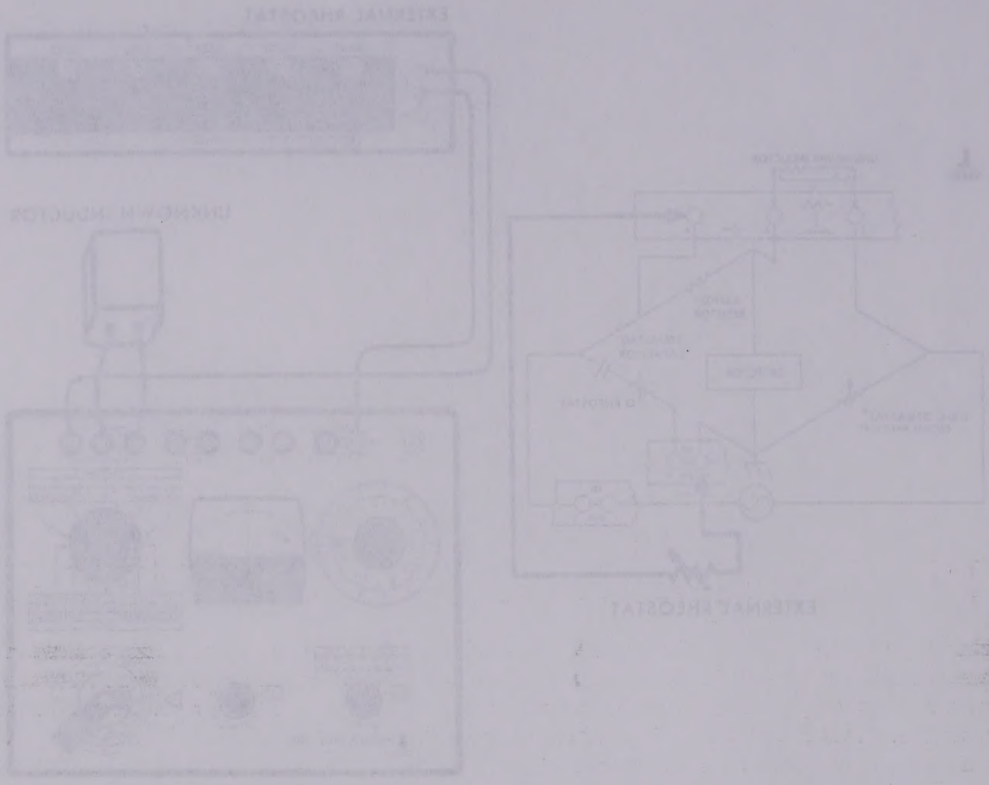
Figure 2-14. Series Inductance, External Q Rheostat

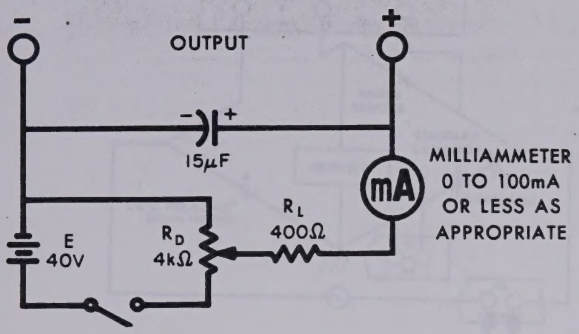
2.7.3 Inductance Measurement Using DC Bias

Iron-core inductors are sensitive to both ac and dc current variations. Quantitative measurements of dc effects can be made with the Model 250DE bridge by supplying current to the unknown inductor through the EXT BIAS terminals.

DC Supply

The dc current should be supplied from a power-limited source in order to prevent damage to the bridge. The power to the bridge should not exceed 1 watt, and the current should not exceed 100 milliamperes during measurement. Higher current will cause distortion of the ac generator output and may result in incorrect measurements.





SUPPLY VOLTAGE E (VOLTS)	LIMITING RESISTOR R_L (OHMS)	VOLTAGE CONTROL R_D (OHMS)
1	10	100
1.5	15	150
2	22	250
3	33	250
4	47	500
4.5	47	500
6	68	750
9	100	1k
12	120	1.5k
15	150	1.5k
22.5	270	2.5k
24	270	2.5k
28	330	3.5k
30	330	3.5k
45	560	5k
67.5	1.2k	10k
90	2.2k	20k
103.5	2.7k	30k
120	3.9k	50k
225	13k	100k
300	27k	250k

Figure 2-15. DC Supply Circuit

The dc supply circuit shown in Figure 2-15 is safe at any bridge setting. Other values of voltage, limiting resistor (R_L) and voltage control (R_D) are given in the table. These values do not necessarily limit the current to less than 100 milliamperes, but they do limit the power to 1 watt. Values shown are for commonly available voltages. The limiting resistors can have tolerances of 20% and should be rated at 5 watts or more. If the proper value of resistor is not available, use a larger value rather than smaller. The voltage control potentiometer may differ from the listed value by a factor of 2. It should be rated at 1 watt or more.

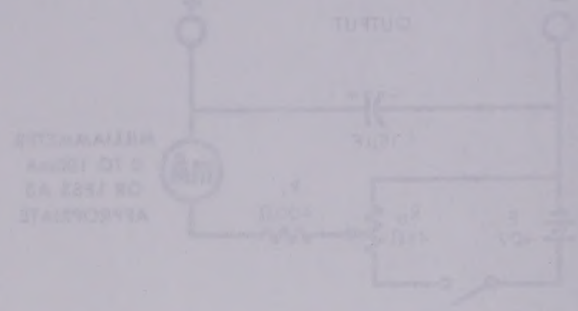
Operating Procedure

1. Set FUNCTION switch to L-PARALLEL or L-SERIES. The L-PARALLEL setting is preferred since in this bridge configuration, the standard capacitor blocks dc current and allows direct measurement of current through the inductor.

2. Connect the unknown inductor to R-L terminals 1 and 2. See Figure 2-16.

3. Remove shorting lug and connect dc bias between EXT BIAS terminals 1 and 2. The shorting lug can be pivoted to one side. See Figure 2-16.

4. For L-PARALLEL: Adjust dc current as required and measure inductance. For L-SERIES: Set current to approximately the desired level and balance the bridge for a first approximation. See Section 2.7.1 for normal procedure. The L-PARALLEL configuration allows direct measurement of current in the inductor.



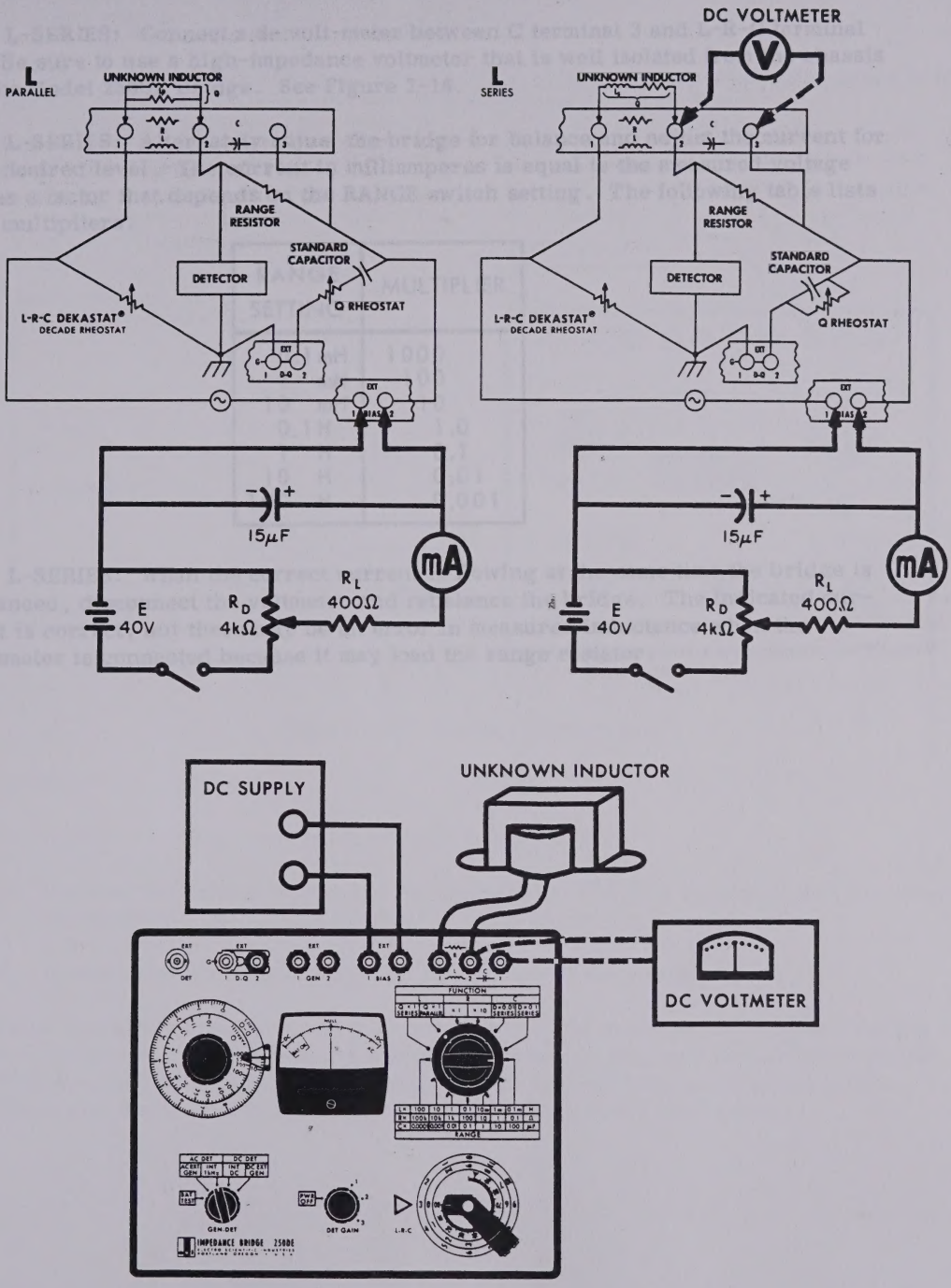
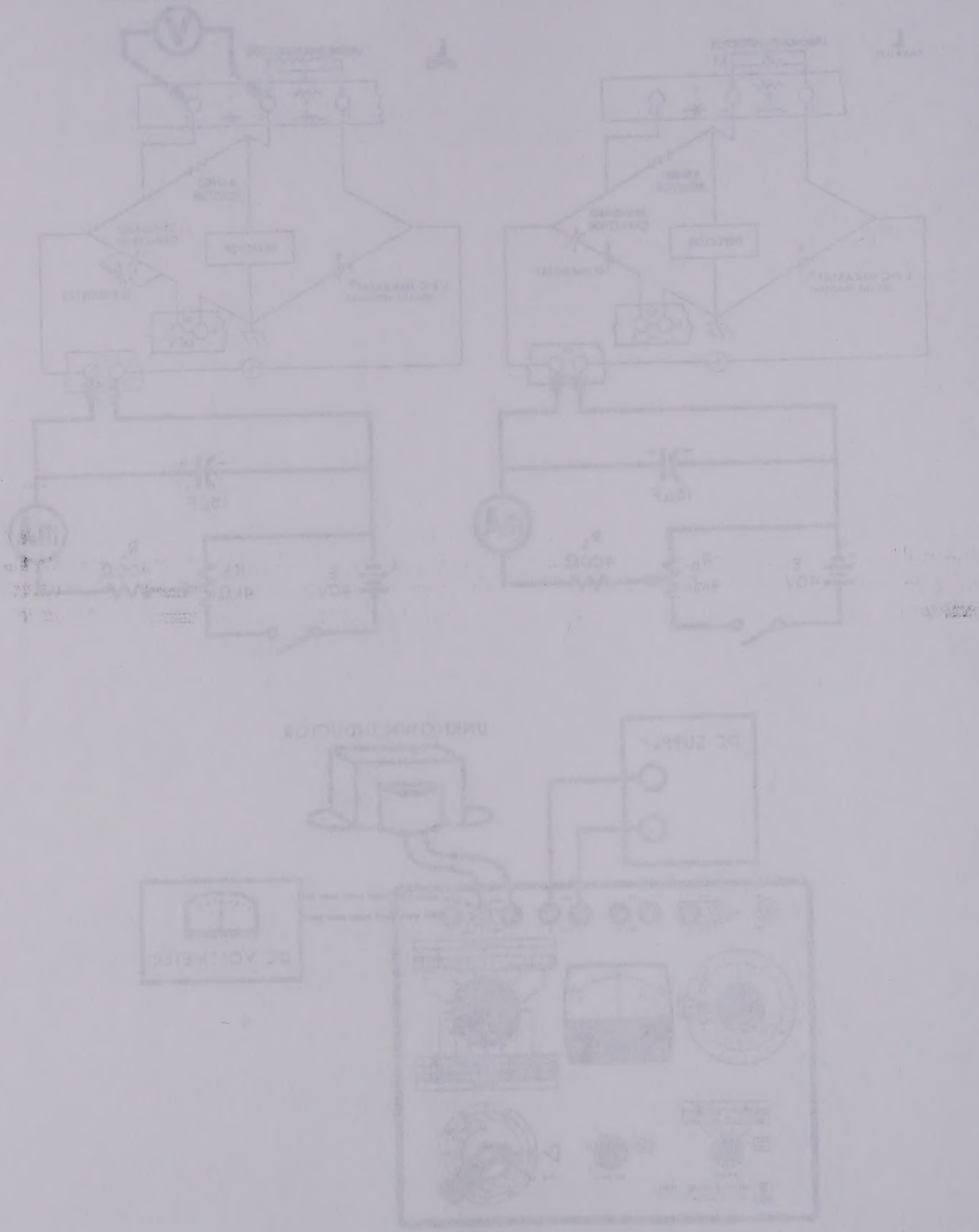


Figure 2-16. Inductance Measurement Using DC Bias



5. For L-SERIES: Connect a dc volt-meter between C terminal 3 and L-R-C terminal 2. Be sure to use a high-impedance voltmeter that is well isolated from the chassis of the Model 250DE Bridge. See Figure 2-16.

6. For L-SERIES: Alternately adjust the bridge for balance and adjust the current for the desired level. The current in milliamperes is equal to the measured voltage times a factor that depends on the RANGE switch setting. The following table lists the multipliers.

RANGE SETTING	MULTIPLIER
0.1 mH	1000
1 mH	100
10 mH	10
0.1 H	1.0
1 H	0.1
10 H	0.01
100 H	0.001

7. For L-SERIES: When the correct current is flowing at the same time the bridge is balanced, disconnect the voltmeter and rebalance the bridge. The indicated current is correct, but there may be an error in measured inductance when the voltmeter is connected because it may load the range resistor.

2.7.4 Voltage and Current in Unknown Inductor

In many cases it is necessary to measure the ac voltage or current in an inductor being tested. Either can be measured with a high-impedance ac voltmeter.

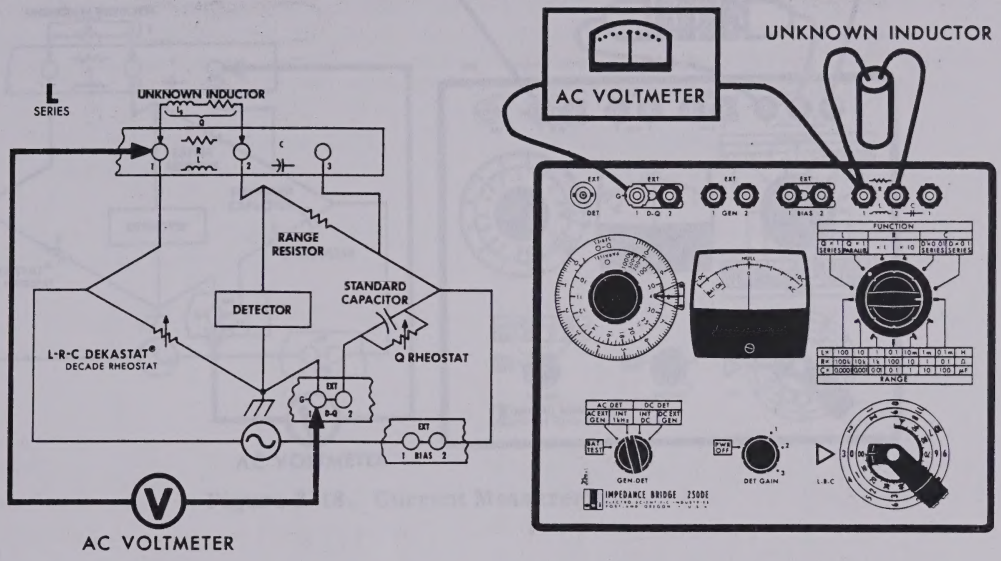


Figure 2-17. Voltage Measurement

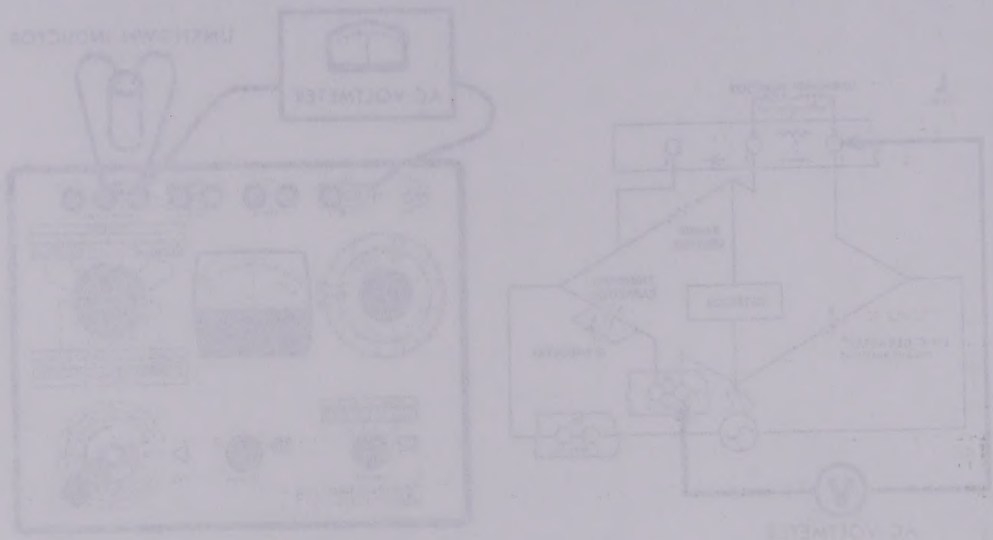
Voltage

To measure ac voltage across an inductor being tested:

1. Connect the ground terminal of the voltmeter to EXT D-Q terminal 1 and the other voltmeter terminal to R-L terminal 1. (See Figure 2-17.)

2. Balance the bridge and then read the voltage on the voltmeter.

Since measuring voltage in this way does not load the inductor, the voltage reading will be correct. The inductance reading of the bridge may be incorrect because the voltmeter may load the L-R-C decades. For the correct inductance measurement, disconnect the voltmeter from the L terminal and rebalance the bridge.


AC VOLTMETER

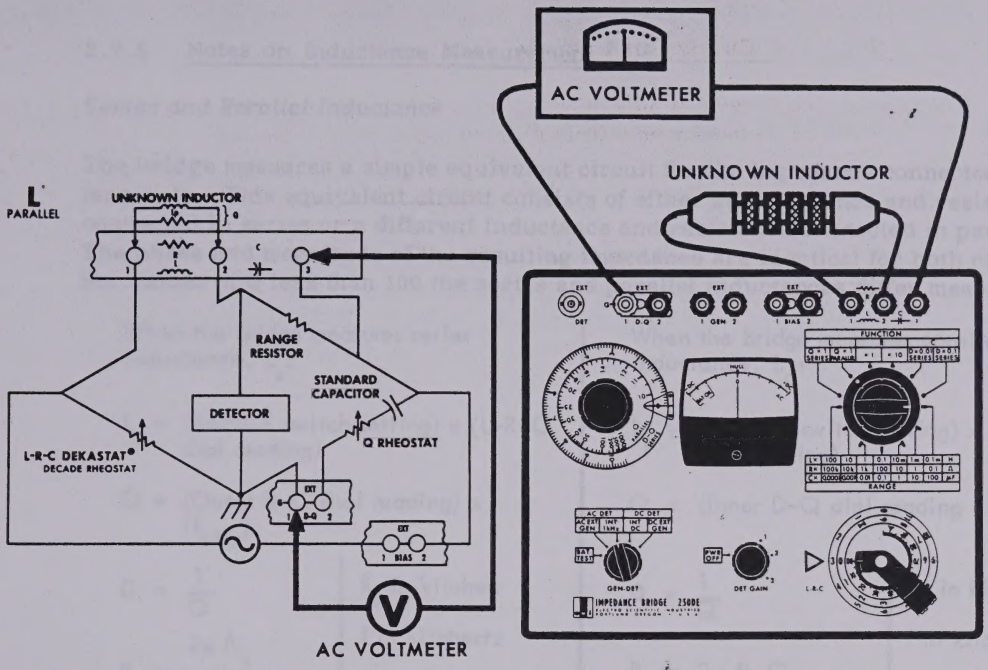


Figure 2-18. Current Measurement

Current

To measure ac current in an inductor being tested:

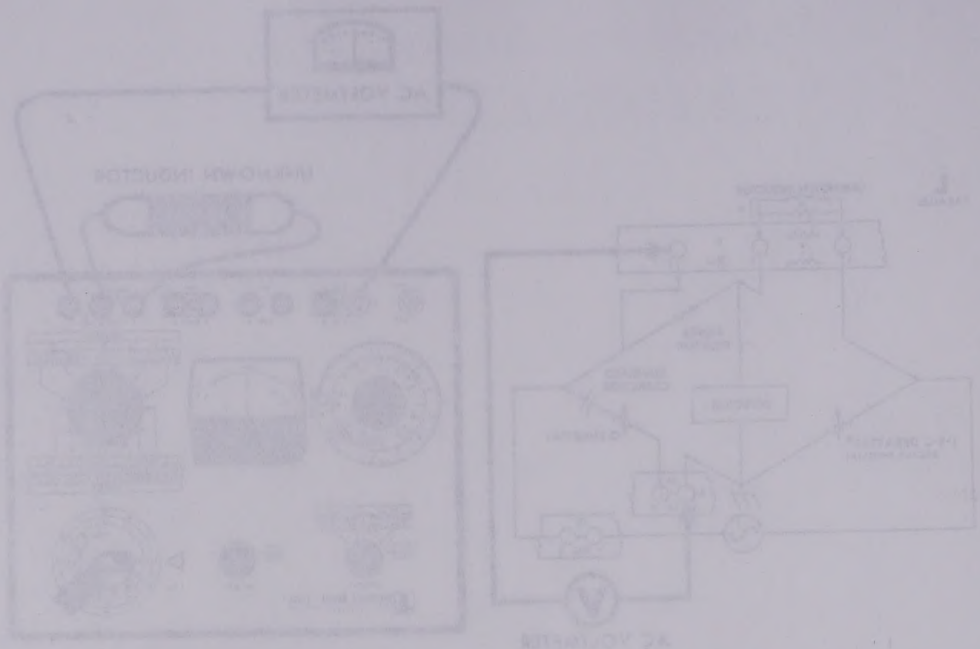
1. Connect the ground terminal of the voltmeter to EXT D-Q terminal 1 and the other voltmeter terminal to C terminal 3 (see Figure 2-18).

2. Balance the bridge and then read the voltage.

3. The current in milliamperes is equal to the measured voltage multiplied by a factor that depends on the RANGE switch setting as shown in the following table.

RANGE SETTING	MULTIPLIER
0.1 mH	1000
1 mH	100
10 mH	10
0.1 H	1.0
1 H	0.1
10 H	0.01
100 H	0.001

The current in milliamperes is correct, but since the voltmeter may load the standard capacitor, the measured inductance may be incorrect when the voltmeter is connected.



2.7.5 Notes on Inductance Measurement

Series and Parallel Inductance

The bridge measures a simple equivalent circuit for the impedance connected to its terminals. This equivalent circuit consists of either an inductance and resistance connected in series or a different inductance and resistance connected in parallel. The phase and magnitude of the resulting impedance are identical for both circuits. For values of Q less than 100 the series and parallel inductances differ measurably.

When the bridge measures series inductance, L_s:

L_s = (RANGE switch setting) x (L-R-C dial reading)

Q = (Outer D-Q dial reading) x (f_{kHz})

$D = \frac{1}{Q}$

$R_s = \frac{2\pi f L_s}{Q}$

$Z = 2\pi f L_s \left(\frac{1}{Q} + j\right)$

R_s in kilohms
f in kilohertz
L_s in henrys
$j = \sqrt{-1}$
Z in kilohms

To calculate the equivalent parallel circuit:

$L_p = \left(1 + \frac{1}{Q^2}\right) L_s$

$R_p = Q(2\pi f L_p)$

When the bridge measures parallel inductance, L_p:

L_p = (RANGE switch setting) x (L-R-C dial reading)

Q = (Inner D-Q dial reading ÷ (f_{kHz})

$D = \frac{1}{Q}$

$R_p = 2\pi f L_p Q$

$Z = \frac{2\pi f L_p Q (1 + jQ)}{1 + Q^2}$

R_p in kilohms
f in kilohertz
L_p in henrys
$j = \sqrt{-1}$
Z in kilohms

To calculate the equivalent series circuit:

$L_s = \left(\frac{Q^2}{1 + Q^2}\right) L_p$

$R_s = \frac{2\pi f L_s}{Q}$

The Q of the equivalent parallel circuit always equals the Q of the equivalent series circuit. The same is true of D.

Low-Inductance Measurements

The bridge measures the total impedance connected to its terminals. Both the unknown inductor and its leads contribute to this impedance. The leads have some resistance and inductance which affect the value read from the bridge.

For greatest accuracy, minimize the lead impedance. Short heavy leads will reduce the resistance and closely spaced, twisted leads will reduce the inductance and the pickup of stray fields.

High-Inductance Measurements

In making high-inductance measurements, there are two things to watch out for:

1. Be careful to avoid ac pickup.
2. Keep the stray capacitance to a minimum.

To minimize both effects keep hands as far as possible from the inductor measured. Keep the leads as short and direct as possible. If extended leads are necessary, the lead from terminal 2 should be shielded. See Section 2.8.2. Take care to avoid coupling stray magnetic fields into the inductor being measured.

2.8 USEFUL MEASUREMENT TECHNIQUES

2.8.1 External Detector

The Model 250DE has provision for connecting an external detector such as an ac or dc microvoltmeter, a galvanometer, or an oscilloscope. The external detector can best be connected to the EXT DET socket which is a BNC coaxial connector as shown in Figure 2-19. Note that the GEN-DET switch does not disconnect the EXT DET connector from the bridge circuit. This allows the internal detector to be used at the same time as the external.

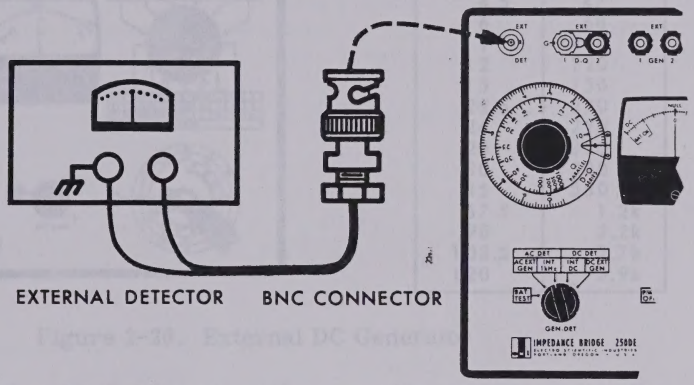


Figure 2-19. External Detector Connection

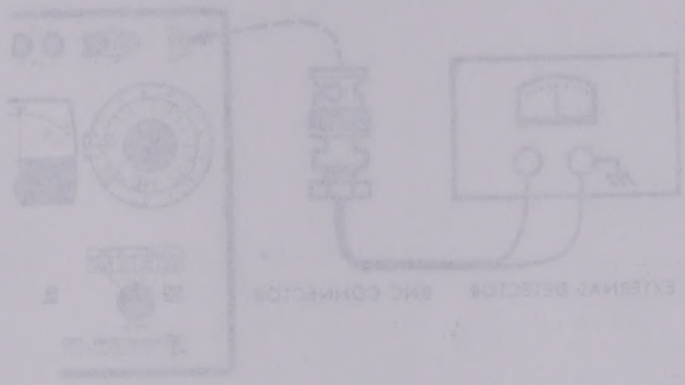
2.8.2 External DC Generator

An external dc generator may be connected to the bridge between EXT GEN terminals 1 and 2 as shown in Figure 2-20. Set the GEN-DET switch to DC EXT GEN to connect the external generator to the bridge and to disconnect the isolation transformer from the circuit.

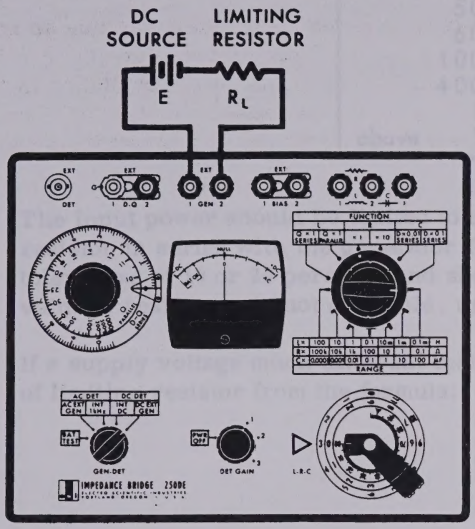
Always use a power-limited dc source. The power in the circuit shown is limited by a resistor R_L. If the value of the resistor is chosen from the accompanying table, the power in the bridge will never exceed one watt, which is always safe. Values shown are for commonly-available voltages. The limiting resistors can have tolerances of 10 or 20 percent, and should be rated at five watts or more. If the proper value of resistance is not available, use a larger value rather than a smaller.

If a supply voltage much different from those listed is to be used, use the following formula to determine the proper value of limiting resistance:

$$R_L = \frac{E^2}{4}$$



Batteries are recommended because many line-operated power supplies have objectionably high leakage to ground. If a line operated supply is to be used, be sure that its insulation resistance to the chassis of the Model 250DE is higher than 10^{10} ohms.



SUPPLY VOLTAGE E (VOLTS)	LIMITING RESISTOR R_L (OHMS)
1	10
1.5	15
2	22
3	33
4	47
4.5	47
6	68
9	100
12	120
15	150
22.5	270
24	270
28	330
30	330
45	560
67.5	1.2k
90	2.2k
103.5	2.7k
120	3.9k

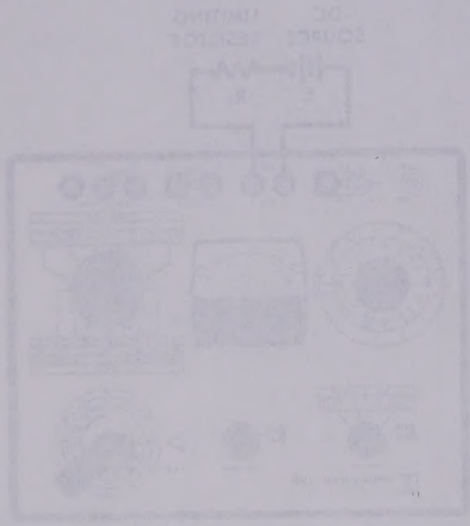
Figure 2-20. External DC Generator

See also Sections 2.6.3 and 2.7.3 for external dc supplies used in conjunction with ac measurements. The dc supplies, especially that of Section 2.6.3, are useful for dc resistance measurement.

2.8.3 External AC Generator

The Model 250DE Impedance Bridge has terminals for connecting an external ac generator. The EXT GEN terminals are connected to the primary winding of an isolation transformer when the GEN-DET switch is in the AC EXT GEN position. Because of this, the external generator may be grounded at EXT GEN terminal 1 without causing ground loops or measurement errors.

The input voltage should be limited to 50 volts or 50 times the generator frequency in kilohertz, whichever is less. Higher voltages will saturate the isolation transformer and will be distorted. A few examples are shown in the following table.

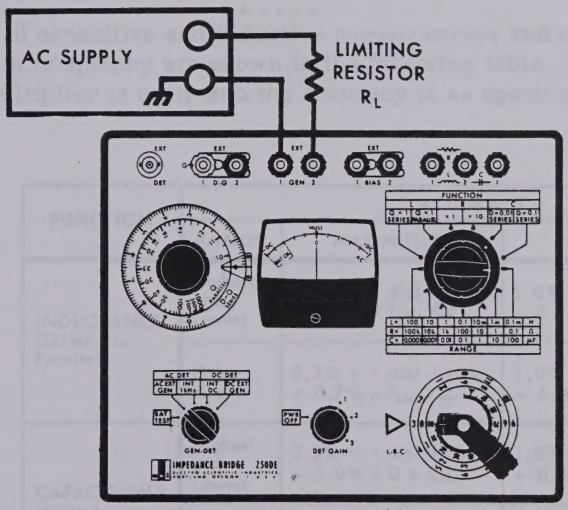


FREQUENCY	MAXIMUM VOLTAGE
50 Hz	2.5V
60 Hz	3.0V
100 Hz	5.0V
400 Hz	20.0V
1 kHz	50.0V
above 1 kHz	50.0V

The input power should be limited to one watt. This can be done easily by inserting a resistor in series with the generator (see Figure 2-21). The resistors listed can have tolerances of 10 or 20 percent, and should be rated at five watts or more. If the proper value of resistance is not available, use a larger value rather than a smaller.

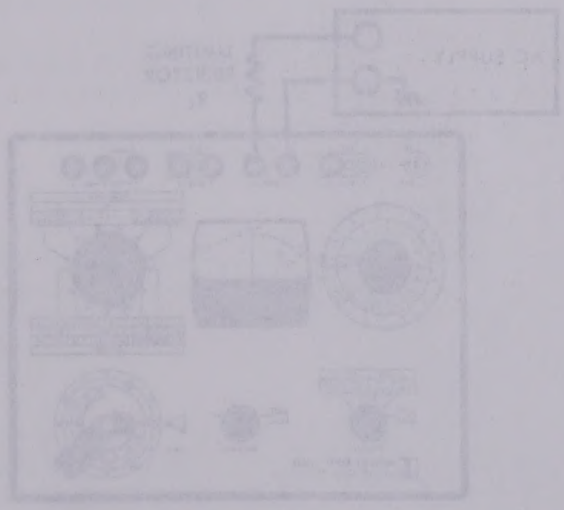
If a supply voltage much different than those listed is to be used, calculate the value of limiting resistor from the formula:

$$R_L = \frac{E^2}{4}$$



SUPPLY VOLTAGE E (VOLTS)	LIMITING RESISTOR R_L (OHMS)
1	0.27
2	1.0
5	6.8
10	27
20	100
50	680

Figure 2-21. External AC Generator



2.8.4 Operation at Frequencies Other Than One Kilohertz

In order to operate the Model 250DE Impedance Bridge at frequencies other than one kilohertz, an external ac generator and detector are required. It goes without saying that the generator and detector must be tuned to the same frequency.

There are two effects that must be taken into consideration at frequencies other than one kilohertz.

1. The dissipation factor (D) and the storage factor (Q) cannot be read directly from the D-Q dial.
2. The specified accuracy of the bridge changes as a function of frequency.

D and Q Corrections

To find the dissipation factor (D) of a capacitor, multiply the D-Q dial setting times the FUNCTION switch setting times the frequency in kilohertz.

To find the storage factor (Q) of an inductor, multiply the outer D-Q dial reading by the frequency in kilohertz, or divide the inner Q dial reading by the frequency in kilohertz. Use the outer dial for series inductors and the inner dial for parallel inductors, exactly as in normal inductance measurements.

Accuracy

Accuracy of capacitive and inductive measurements and of D and Q measurements as functions of frequency are shown in the following table. At one kilohertz, the frequency multiplier is unity and the accuracy is as specified in paragraph 1.2.

FUNCTION	ACCURACY		
	RANGE	MAGNITUDE	D OR Q
INDUCTANCE (Series and Parallel)	Highest and Lowest	0.2% + 1 dial division + 1.2% x f_{kHz} /Q	1.0% + 1 dial division + 0.012 (1 + $1/Q^2$) x f_{kHz}
	Other Five	0.2% + 1 dial division + 0.7% x f_{kHz} /Q	1.0% + 1 dial division + 0.007 (1 + $1/Q^2$) x f_{kHz}
CAPACITANCE (Series)	Highest and Lowest	0.2% + 1 dial division + 1.0% x D x f_{kHz}	1.0% + 1 dial division + 0.01 (1 + D^2) x f_{kHz}
	Other Five	0.2% + 1 dial division + 0.5% x D x f_{kHz}	1.0% + 1 dial division + 0.005 (1 + D^2) x f_{kHz}

2.8.5 Sliding Balance

When lossy capacitors and inductors are measured, the nulling problem known as sliding balance can occur. This problem is most frequently encountered in inductors. It is not too serious if the Q of an inductor is greater than 1 or if the D of a capacitor is less than 1. In either case, an external D-Q rheostat may be necessary.

The problem becomes apparent when the instrument seems to have false nulls at different settings of the R-L-C decade dials and the D-Q dial. Figure 2-22 illustrates the cause of the difficulty.

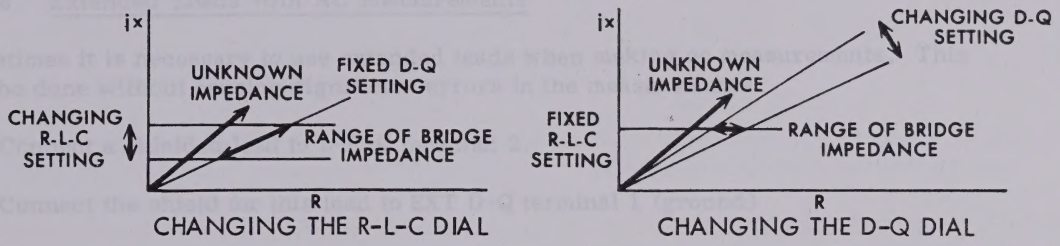


Figure 2-22. Sliding Balance

If the unknown impedance and the bridge impedance are considered as vectors, the bridge is balanced when the vectors are equal. The L-R-C decade dials change the vector of the bridge impedance only along the R axis, and the D-Q dial changes the angle of the vector of the bridge impedance. If the angle of the unknown impedance vector is not steep, the L-R-C decades and the D-Q dial operate nearly perpendicular to each other and there is little or no difficulty. (This is the case of low D or High Q.)

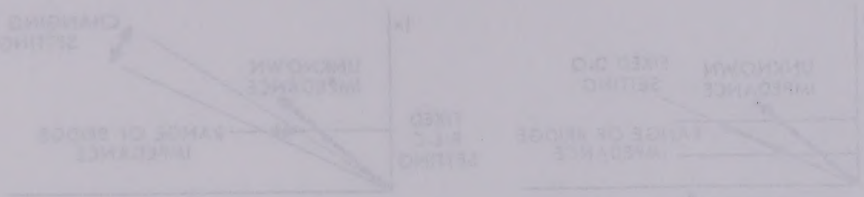
If the D of a capacitor is high or the Q of an inductor is low, the vector of the unknown impedance has such a steep angle that the dials no longer move the bridge impedance vector directly to a null.

The following technique will allow rapid and accurate measurements with sliding balance.

1. Make a preliminary measurement using the techniques described in paragraph 2.6.1 for capacitors, paragraph 2.7.1 for inductors. This gives a first approximation. The null at this point may not be very sharp.

2. Adjust DET GAIN control so that meter pointer is on third long mark to right of 0. This sets a reference level on the detector. As the null comes closer, use marks closer to 0.

3. Turn the inner L-R-C dial a small amount in one direction, then adjust D-Q dial for minimum detector deflection. Turn one switch step of the outer dial at first. Use smaller steps when the null is close.



4. Note the reading on the meter. If it is closer to 0, repeat steps 2 and 3, turning L-R-C dial in the same direction. If the reading is further from 0, repeat steps 2 and 3, turning L-R-C dial in the opposite direction. This procedure should converge to a sharp null. Each step should be shorter than the last when the null is close.

5. When the null is close, turn the D-Q dial part of a dial division at a time and adjust L-R-C dial for best null. Watch out for false nulls at the ends of the range of the instrument, especially at low settings of the series inductive circuit. When the D-Q dial and the L-R-C dials are both at zero in the series inductive circuits, the generator is short circuited and the bridge indicates null.

2.8.6 Extended Leads With AC Measurements

Sometimes it is necessary to use extended leads when making ac measurements. This can be done without causing significant errors in the measurements.

1. Connect a shielded lead to L-R-C terminal 2.

2. Connect the shield for this lead to EXT D-Q terminal 1 (ground).

3. Connect an unshielded lead to C terminal 3 for capacitive measurements, to L-R terminal 1 for inductive measurements.

4. Connect the capacitance or inductance to be measured between the shielded and unshielded lead.

When the leads are connected in this manner, the capacitance between the shielded lead and the shield is across the detector, and will not cause errors in measurement. In the capacitance-measuring circuit, the stray capacitance from the unshielded lead to ground is across the 100-nF standard capacitor, and will not cause significant errors unless it is more than 10 pF. In the inductance-measuring circuit, the stray capacitance of the unshielded lead is across the L-R-C decade rheostat, and will cause no significant errors if it is less than 1 pF. If the L-R-C decade setting is less than 1.0, 10-pF stray capacitance will cause no significant error.

2.8.7 Mechanical Zero Adjustment

If the pointer on the meter becomes misaligned, reset it as follows:

1. Turn on power with DET GAIN control. Leave the control set for minimum gain; as far counterclockwise as possible without turning instrument off.

2. Set GEN-DET switch to DC EXT GEN.

3. Adjust the meter zeroing screw on the meter for null indication.

On some instruments, the meter may not indicate zero when power is off. This is unimportant as long as it indicates zero when the power is on but the generator is off.

SECTION 3

MAINTENANCE

3.1 INTRODUCTION

This section describes routine maintenance of the ESI Model 250DE Impedance Bridge. The performance check shows whether the instrument is operating within the limit of accuracy listed in Table 1-1. Some instrument failures can be easily diagnosed and treated; these are discussed in this section. If the instrument is operating improperly and the malfunction is not discussed here, it should be returned to the ESI factory for repair and recalibration.

3.2 PERFORMANCE CHECK

It is presumed that the operator is familiar with the Model 250DE Impedance Bridge and with the equipment referred to in this section. Brief instructions for operating the bridge are inside the lid.

Whenever the instruction "measure" is given in this procedure, it means to operate the bridge under test as a measurement system.

The procedures in this section are for use with the equipment recommended in Section 3.2.2. Control and terminal nomenclature refer specifically to this equipment. If other equipment is used, be sure to note differences and revise the process accordingly. All connections to the instrument are made to R-L binding posts 1 and 2 or to C binding posts 2 and 3. Figure 3-1 shows the front panel of the instrument and the binding posts.

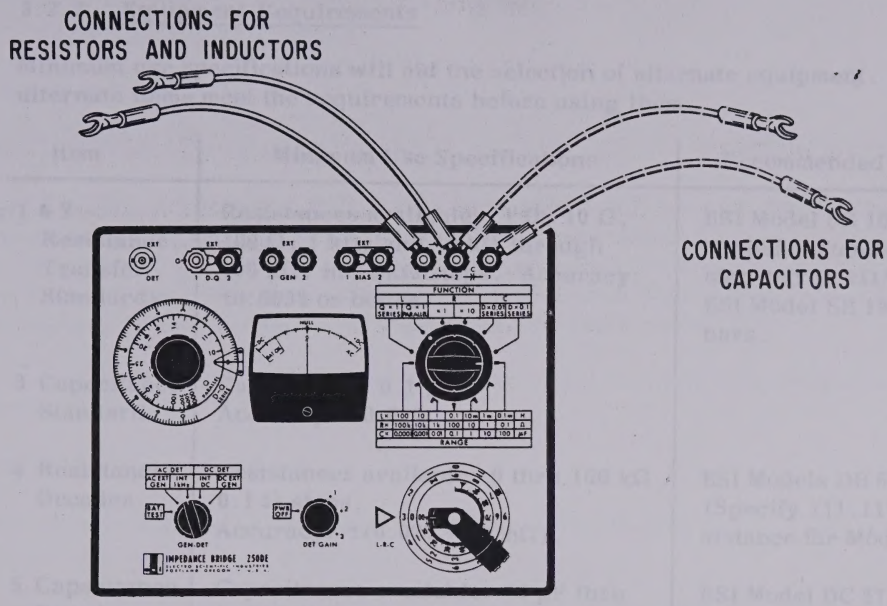
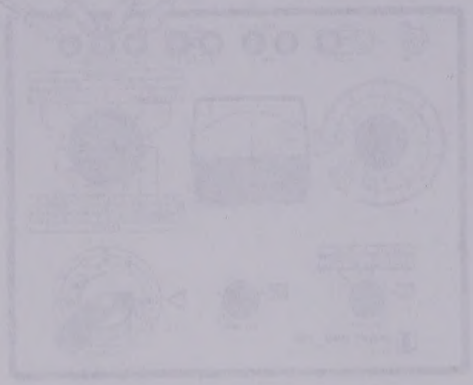


Figure 3-1. Model 250DE Impedance Bridge

3.2.1 Checking Method

The method used to check the ESI Model 250DE Bridge is outlined in the following table:

Item Under Test	Performance Specifications	Test Method
Resistance Range	0.1%	Measurements of standard resistances.
MAIN DIAL Linearity Calibration	0.1% + 1 dial division	Measurements of series-connected resistance transfer standards and resistance decades.
Capacitance Calibration	0.1%	Measurement of standard capacitor.
D-Q Dial Linearity	1.0% + 1 dial division +0.005 $(1 + D^2)$ 1.0% + 1 Dial division +0.007 $(1 + 1/Q^2)$	Measurements of resistance-capacitance combinations.
Functional Tests	Bridge Balance on SERIES and PARALLEL inductances.	Measurement of inductances.



3.2.2 Equipment Requirements

Minimum use specifications will aid the selection of alternate equipment. Be sure alternate items meet the requirements before using them.

Item	Minimum Use Specifications	Recommended Equipment
1 & 2 Resistance, Transfer Standards	Resistances available: 1 Ω, 10 Ω, 100 Ω, 1 kΩ, and 10 kΩ through 120 kΩ, in 10 kΩ steps. Accuracy: ±0.003% or better.	ESI Model SR 1010 Resistance Transfer Standards (10 Ω/step and 10 kΩ/step) with ESI Model SB 103 shorting bars.
3 Capacitance Standard	Capacitance: 0.1 μF. Accuracy: ±0.02%.	
4 Resistance Decades	Resistances available: 0 thru 100 kΩ 0.1 Ω steps. Accuracy: ±(0.02% + 10 mΩ).	ESI Models DB 62 or DB 877. (Specify 111.111 kΩ total resistance for Model DB 62).
5 Capacitance Decades	Capacitances available: 10 pF thru 1 μF with 5-dial resolution. Dissipation factor: less than 2.5×10^{-4}.	ESI Model DC 57
6 Inductor	Inductance: 100 mH. Minimum Q: 10.	
7 Test Leads		ESI part numbers 4160 and 4168 (Supplied with Model 250DE)

3.2.3 Preparation

Remove lid from instrument and set GEN DET switch to BAT. TEST. Meter should deflect to BAT. OK zone. If not, replace batteries.* Battery replacement procedure is outlined on the instruction sheet on the inside of the instrument cover.

3.2.4 Environmental Conditions

For highest accuracy, the temperature should be 23°C ±2° (73°F ±4°). If the temperature is outside these limits, apply temperature coefficient corrections to find correct values of standard resistors and capacitors.

*If the instrument is equipped with a Model 1325 Power Pac, plug it in to charge the batteries.

3.2.5 Resistance Range Check

0.1-Ohm Range

1. Set FUNCTION selector to R x 1.

2. Set GEN-DET switch to INT DC. It should remain in this position throughout resistance range calibration and L-R-C decade calibration.

3. Connect test leads to R-L binding posts 1 and 2. They should remain so connected throughout range resistance calibration and L-R-C dial calibration.

4. Connect R1 through R10 of 10 Ω/step transfer standard (Item 1) in parallel with the shorting bars.

5. Set RANGE selector to 0.1 Ω.

6. Connect one test lead to each terminal on one of the shorting bars. (This allows the zero resistance to be measured.)

7. Measure the zero resistance and record the value in the space provided on the calibration record (Appendix A).

8. Connect one test lead to each shorting bar and measure resistance of the parallel-connected transfer standard. Record the measured value in the space provided on the calibration record.

9. Subtract the zero resistance from the measured resistance and record the difference in the space provided on the calibration record. The difference should be between 0.999 Ω and 1.0010 Ω.

1-Ohm Range

1. Set RANGE selector to 1 Ω.

2. Disconnect shorting bars from transfer standard and connect test leads to terminals A0 and C1 of 10 Ω/step transfer standard. This connects one 10-ohm resistor to the UNKNOWN terminals of the bridge.

3. Measure the resistance of the 10-ohm resistor and record the value in the space provided on the calibration record.

4. Subtract the zero resistance from the measured resistance and record the difference in the space provided on the calibration record. The difference should be between 9.990 Ω and 10.010 Ω.

10-Ohm Range

1. Set RANGE selector to 10 Ω.

2. Disconnect test lead from terminal C1 of the 10 Ω/step transfer standard and connect it to terminal A10. This connects ten 10-ohm resistors in series to the UNKNOWN terminals of the bridge.

3. Measure the resistance of the series-connected transfer standard and record the value in the space provided on the calibration record.

4. Subtract the zero resistance from the measured resistance and record the difference in the space provided on the calibration record. The difference should be between 99.90 Ω and 100.1 Ω.

100-Ohm Range

1. Set RANGE selector to 100 Ω.

2. Connect R1 through R10 of the 10 kΩ/step transfer standard in parallel with the shorting bars.

3. Disconnect test leads from 10 Ω/step transfer standard and connect one test lead to each shorting bar on the 10 Ω/step transfer standard.

4. Measure the resistance of the parallel-connected transfer standard and record the value in the space provided on the calibration record. The measured value should be between 999.0 Ω and 1001.0 Ω. (From this point on, zero resistance is not subtracted because it is insignificant compared to the tolerance.)

1-Kilohm Range

1. Set RANGE selector to 1 kΩ.

2. Disconnect shorting bars from transfer standard and connect test leads to terminals A0 and C1 of the 10 kΩ/step transfer standards. (This connects one 10-kilohm resistor to the UNKNOWN terminals of the bridge.)

3. Measure the resistance of the 10-kilohm resistor and record the value in the space provided on the calibration record. The measured value should be between 9.990 kΩ and 10.010 kΩ.

10-Kilohm Range

1. Set RANGE selector to 10 kΩ.

2. Disconnect test lead from terminals C1 of the 10 kΩ/step transfer standard and connect it to terminal A10. This connects ten 10-kilohm resistors in series to the UNKNOWN terminals of the bridge.

3. Measure the resistance of the series-connected transfer standard and record the value in the space provided on the calibration record. The measured value should be between 99.90 kΩ and 100.10 kΩ.

100-Kilohm Range

1. Set RANGE selector to 100 kΩ.

2. Measure the resistance of the series-connected transfer standard on this range. Record the measured value in the space provided on the calibration record. The measured value should be between 99.90 kΩ and 100.1 kΩ.

R x 10 Range

1. Set FUNCTION selector to R x 10.

2. Set RANGE selector to 1 kΩ.

3. Measure the resistance of the series-connected transfer standard and record the value in the space provided on the calibration record. The measured value should be between 99.90 kΩ and 100.10 kΩ.

Table 3-1. First Dial Calibration

		Dial Setting Tolerances	
1	2	3	4
First Dial Setting	Transfer Standard Resistance	Upper Limit	Lower Limit
0	10kΩ	0.X02	0.998
1	20kΩ	1.X03	1.997
2	30kΩ	2.X04	2.996
3	40kΩ	3.X05	3.995
4	50kΩ	4.X06	4.994
5	60kΩ	5.X07	5.993
6	70kΩ	6.X08	6.992
7	80kΩ	7.X09	7.991
8	90kΩ	8.X10	8.990
9	100kΩ	9.X11	9.989
10	110kΩ	10.X12	10.988
11	120kΩ	11.X13	11.987

Table 3-2. Second Dial Calibration

		Dial Setting Tolerances	
1	2	3	4
Second Dial Setting	Transfer Standard Resistance	Upper Limit	Lower Limit
0	10Ω	0.0(101)	0.099
1	20Ω	0.1(101)	0.199
2	30Ω	0.2(101)	0.299
3	40Ω	0.3(101)	0.399
4	50Ω	0.4(101)	0.499
5	60Ω	0.5(102)	0.598
6	70Ω	0.6(102)	0.698
7	80Ω	0.7(102)	0.798
8	90Ω	0.8(102)	0.898
9	100Ω	0.9(103)	0.997
X	110Ω	0 X(104)	0.X96

Table 3-3. Third Dial Calibration

		Dial Setting Tolerances	
1	2	3	4
Third Dial Setting	Transfer Standard Resistance	Upper Limit	Lower Limit
10	10Ω	0.011	0.009
20	20Ω	0.021	0.019
30	30Ω	0.031	0.029
40	40Ω	0.041	0.039
50	50Ω	0.051	0.049
60	60Ω	0.061	0.059
70	70Ω	0.071	0.069
80	80Ω	0.081	0.079
90	90Ω	0.091	0.089
*0	100Ω	0.0(101)	0.099

3.2.6 L-R-C Dial Check

First Dial

1. Set RANGE selector to 10 kΩ.
   NOTE: The next three steps are repeated for each setting of the first L-R-C dial. Refer to Table 3-1 for nominal dial settings, standard resistance values, and dial-setting tolerances.

2. Set first (outer) dial to the setting listed in column 1 of Table 3-1.

3. Connect test leads to 10 kΩ/step transfer standard in such a way that the resistance listed in column 2 of Table 3-1 is connected to UNKNOWN terminals.

4. Balance the bridge without changing position of first dial. Record L-R-C dial setting in the space provided on the calibration record. The upper and lower limits of this dial setting are listed in columns 3 and 4 of Table 3-1.

Second Dial

1. Set RANGE dial to 100 Ω.

2. Set first (outer) dial to 0.
   NOTE: The next three steps are repeated for each setting of the second L-R-C dial. Refer to Table 3-2 for nominal dial settings, standard resistance values, and dial setting tolerances.

3. Set second dial to the setting listed in column 1 of Table 3-2.

4. Connect test leads to 10 Ω/step transfer standard in such a way that the resistance listed in column 2 of Table 3-2 is connected to UNKNOWN terminals.

5. Balance the bridge without changing position of second dial. Record L-R-C dial setting in the space provided on the calibration record. The upper and lower limits of this dial setting are listed in columns 3 and 4 of Table 3-2.

Third Dial

1. Set RANGE dial to 1 kΩ.

2. Set first (outer) dial to 0.

3. Set second dial to 0.
   NOTE: The next two steps are repeated for each setting of the third L-R-C dial Refer to Table 3-3 for nominal dial settings, standard resistance values and dial-setting tolerances.

4. Connect test leads to 10 Ω/step transfer standard in such a way that the resista listed in column 2 of Table 3-3 is connected to UNKNOWN terminals.

5. Balance the bridge with third dial only. Record L-R-C dial setting in the spa provided on the calibration record. The upper and lower limits of this dial setting are listed in columns 3 and 4 of Table 3-3.

3.2.7 Capacitance Check

1. Connect the test leads to C binding posts 2 and 3. They should remain so connected throughout capacitance calibration check and D-Q dial linearity calibration check.

2. Set GEN-DET switch to INT 1 kHz. It should remain in this position for the remainder of the procedure.

3. Set FUNCTION switch to C, D x 0.01.

4. Connect the test leads to the standard capacitor (Item 3).

5. Measure ths standard capacitor and record the reading in the space provided in the data table. Value should be within 11 divisions of the third L-R-C decade dial of the calibrated value of the standard capacitor.

6. If dial reading is not within the specified tolerance, the trim capacitor may need adjustment. See Section 3.6.

3.2.8 D-Q Dial Linearity Check

1. Set FUNCTION dial to C, D x 0.01.

2. Connect resistance decade and capacitance decade (Items 4 and 5) in series and connect to test leads.

3. Set RANGE selector to 0.01 μF and set L-R-C dial to 10.000.
   NOTE: The next four steps are repeated ten times for both D-Q dial ranges. Refer to Table 3-4 for resistance decade settings, nominal D-Q dial settings, and dial-setting tolerances.

4. Set capacitance decade to 99.999 nF.

5. Set resistance decade to setting listed in column 2 of Table 3-4.

6. Alternately adjust D-Q dial and capacitance decade for sharpest null. Do not adjust L-R-C dial or resistance decade. Do not be too concerned with the relative insensitivity of the bridge to capacitance change at high D-Q dial settings. Reduce detector gain as necessary and concentrate on balancing D-Q dial.

7. Record D-Q dial setting in space provided on calibration record. The upper and lower limits of this dial setting are listed in columns 3 and 4 of Table 3-4.

Table 3-4. D-Q Dial Check

Funtion Range	Nominal D-Q Dial Setting	Resistance Decade Setting	D-Q Setting Tolerances	
			Upper Limit	Lower Limit
D x 0.01	1	15.9 Ω	1.11	0.89
	2	31.8 Ω	2.12	1.88
	3	47.7 Ω	3.13	2.87
	4	63.7 Ω	4.14	3.86
	5	79.6 Ω	5.15	4.85
	6	95.5 Ω	6.16	5.84
	7	111.4 Ω	7.17	6.83
	8	127.3 Ω	8.18	7.82
	9	143.2 Ω	9.19	8.81
	10	159.2 Ω	10.20	9.80
D x 0.1	1	159 Ω	1.11	0.89
	2	318 Ω	2.12	1.88
	3	477 Ω	3.13	2.87
	4	637 Ω	4.14	3.86
	5	796 Ω	5.15	4.85
	6	955 Ω	6.16	5.84
	7	1114 Ω	7.17	6.83
	8	1273 Ω	8.18	7.82
	9	1432 Ω	9.19	8.81
	10	1592 Ω	10.20	9.80

3.2.9 Functional Tests

NOTE: There is no accuracy requirement in the following tests. Just be sure that it is possible to balance the bridge with the FUNCTION control in both listed positions.

1. Set FUNCTION selector to L PARALLEL.
2. Set RANGE control to 0.1 H.
3. Connect 100-millihenry inductor (Item 6) to UNKNOWN terminals.
4. Measure inductance of inductor. It should be 0.1 Henry.
5. Set FUNCTION selector to L SERIES.
6. Connect resistance decade (Item 5) in series with inductance.
7. Set resistance decade to 638 ohms.
8. Measure inductance of inductor. It should be approximately 0.1 Henry and the Q should be approximately 1.

3.3 REMOVAL OF INSTRUMENT FROM CASE

1. Remove the phillips head screw from lower back of case (batteries need not be removed).

2. Carefully pull the front panel of the instrument away from the case. The catch on the upper back of this panel is released by pulling the lower part of the panel out ahead of the upper part.

3. The panel may be moved about 15 cm (6 in.) from the case without removing the plug that connects the batteries to the instrument. This plug is removed by carefully pulling it out of the socket in back of the instrument panel.

3.4 REPLACING INSTRUMENT IN CASE

1. Make certain plug connecting battery to instrument is firmly in its socket.

2. Insert instrument into case making certain that the upper catch is properly secured beneath the inside rim of the case. This is accomplished by first placing the upper portion of the front panel into the case and pushing up on the bottom of the panel until it snaps into place.

3. Replace the phillips screw in the back of the case.

3.5 CLEANING PRINTED CIRCUIT BOARD CONTACTS

Occasionally the contacts on the printed circuit board become dirty, resulting in loss of contact between the board and the remainder of the circuit. The most common symptom is an unusually large misalignment of the pointer in the meter when pointer alignment is checked (see Section 2.4). To clean the contacts, proceed as follows:

1. Remove instrument from case (see Section 3.3).

2. Remove two phillips screws from upper section of printed circuit board. Carefully pull board assembly out of socket.

3. Use a soft pencil eraser to erase dirt from contacts on the board.

4. Clean the contacts with freon or methanol to remove grit left by the eraser.

5. Clean socket contacts with freon or methanol.

6. Replace board in the socket and replace the phillips screws.

7. Replace the instrument in its case (see Section 3.4).

3.6 ADJUSTING TRIM CAPACITOR

Adjustment of the trimming capacitor, C11, may be necessary to compensate for drift of the standard capacitor, C1, due to age. When the result of the capacitance calibration check, Section 3.2.7 (Step 5), is not within the specified tolerance of 11 dial divisions, the trim capacitor may be adjusted to correct the error. The procedure for adjustment of the trimming capacitor is as follows:

1. Remove instrument from case, leaving battery plug in place (see Section 3.3).

2. Set GEN-DET switch to INT 1 kHz.

3. Set FUNCTION switch to C, D x 0.01.

4. Set RANGE switch to 0.1 μF.

5. Set L-R-C dial to 1.000.

6. Connect test leads to C binding posts 2 and 3 and to 0.1 μF, standard capacitor (Item 3, Section 3.2.2).

7. Adjust D-Q dial and trim capacitor (attached to standard capacitor which is located above the transformer) alternately until null is obtained on meter.

   NOTE: The trim capacitor is a three-turn trimmer which has a range of about 260 pF to 1300 pF. If the meter cannot be nulled by adjustment of this capacitor, the padding capacitor, C13 may have to be changed. When changing padding capacitor the new capacitor should be a mica capacitor chosen so that the trim capacitor is adjusted near the center of its range when the meter nulls. This provides for future adjustment of the trimmer without further changes of the padding capacitor.

8. Remove test leads from instrument and carefully place instrument back into case (Section 3.4).

SECTION 4

PARTS LIST AND SCHEMATIC DIAGRAM

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
A1	Assembly, Dekatstat Decade Rheostat, L-R-C	230-13248
A2	Assembly, Generator-Detector	505-13216
BT1-BT4	Battery, 1.5 V, D Size	339-05267
C1	Standard Capacitor Assembly	318-18641
	Capacitor, Trimmer, 260-1300 pF	316-18642
	Capacitor, Mica, Selected	
C2	Capacitor, 180 μF, 6 V	314-06474
C3	Capacitor, 1000 μF, 10 V	314-13317
C4	Capacitor, 0.47 μF, ±10%	313-13238
C5	Capacitor, 0.047 μF, ±10%	313-01776
C6	Capacitor, 0.0047 μF, ±10%	313-13299
C7	Capacitor, 510 pF, ±5%	312-44711
C8	Capacitor, 50 pF, ±5%	312-02132
C9	Capacitor, 4 pF, ±10%	311-02126
C10	Capacitor, 0.01 μF, 100 V	313-12260
C11	Capacitor, 100 μF, 12 V	314-06157
CR1, CR2	Diode, 1N276	321-13287
J1	Connector, BNC	504-13255
M1	Meter	337-19036
Q1-Q8, Q10, Q11	Transistor, 2N2925	321-06467
Q9, Q12	Transistor, 2N1307	321-13243
Q13	Transistor, 2N1306	321-13242
R1	Resistor, 140 kΩ, ½ Watt, 1%	305-01631
R2, S2	Potentiometer Switch, 1 MΩ, DET GAIN, PWR OFF	306-13253
R3	Assembly, Triple Rheostat, D-Q	318-13249
R4	Resistor, 1 Ω	240-13296
R5	Resistor, 10 Ω	240-13297
R6	Resistor, 100 Ω	240-13261
R7, R11	Resistor, 1 kΩ	240-13274
R8, R12	Resistor, 10 kΩ	240-13276
R9	Resistor, 100 kΩ	240-13298
R10	Resistor, 1 MΩ	240-02001
R100	Resistor, 1 kΩ	240-73089
R101-R105	Resistor, 2 kΩ	240-73088
R110	Resistor, 100 Ω	240-73091
R111-R115	Resistor, 200 Ω	240-73090
S1	Switch, GEN-DET	201-13207
S3	Switch, RANGE and FUNCTION	230-13250
T1	Transformer	340-13273

SECTION 4

PARTS LIST AND SCHEMATIC DIAGRAM

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
	Battery Clips	339-06564
	Tube, Battery	339-06840
	Binding Post Cap, Black	112-01170
	Binding Post Cap, Gold	112-01172
	Dial, 0-X	102-04775
	Dial, 0-11	101-75292
	Dial, Rheostat, 105 Div.	103-04970
	Dial, D-Q	101-13197
	Dial, FUNCTION	102-04480
	Knob, D-Q	110-01271
	Knob, Large Bar, Filled	110-01266
	Knob, Small Round, DET GAIN	110-01268
	Knob, Small Bar, GEN-DET	110-01270
	Index, D-Q, Triangle	120-13196
	Index, L-R-C	120-73019
	Instruction Sheet, Short Form	130-13204
	Lid, Without Short Form Instructions	720-13316
	Case	703-13319
	Front Panel, 250DE	708-13206
	Plug, 3 Terminal	504-13279
	Socket, 3 Terminal	504-13280
	Test Lead, Red	520-04148
	Test Lead, Black	520-04160

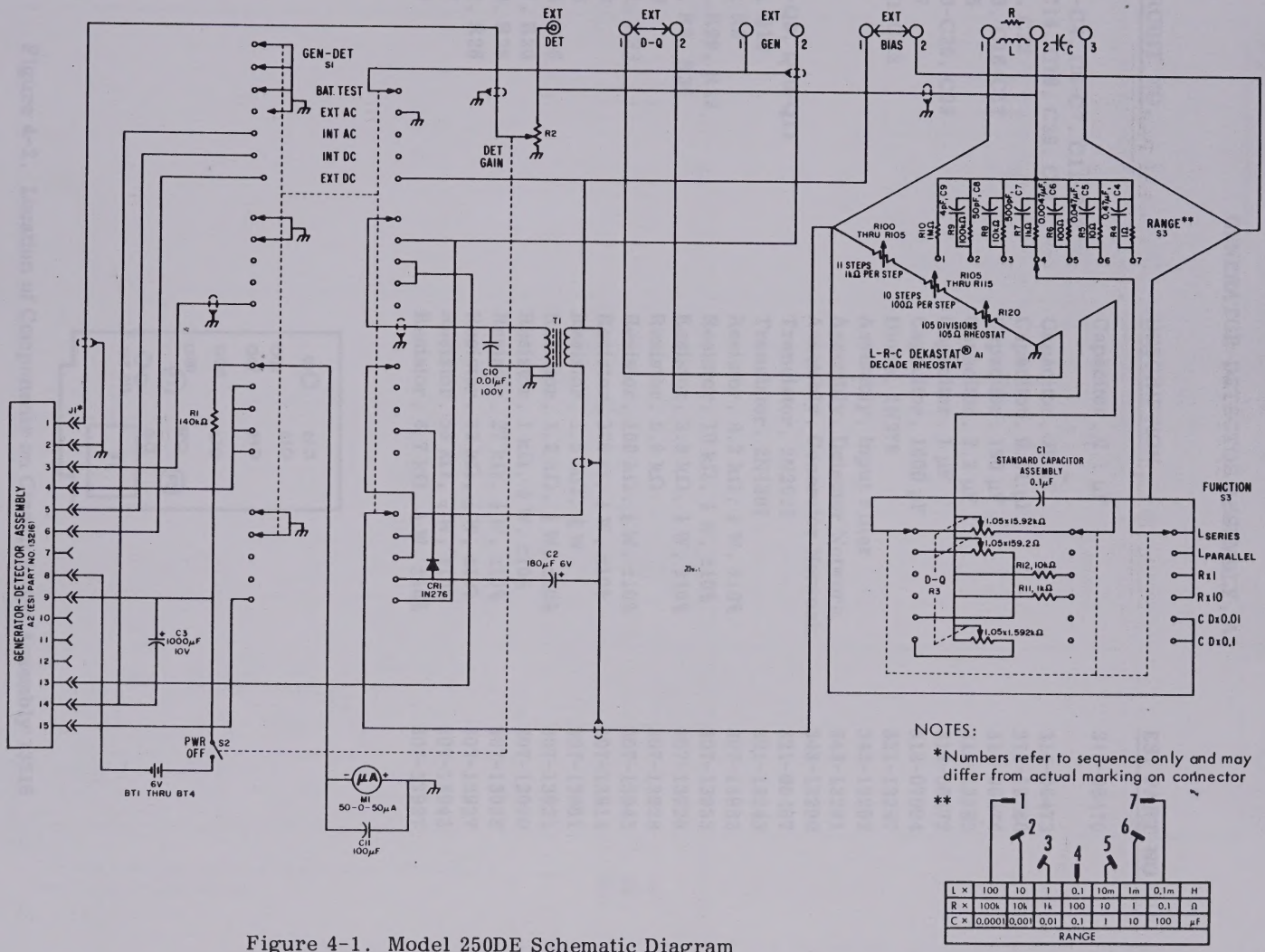
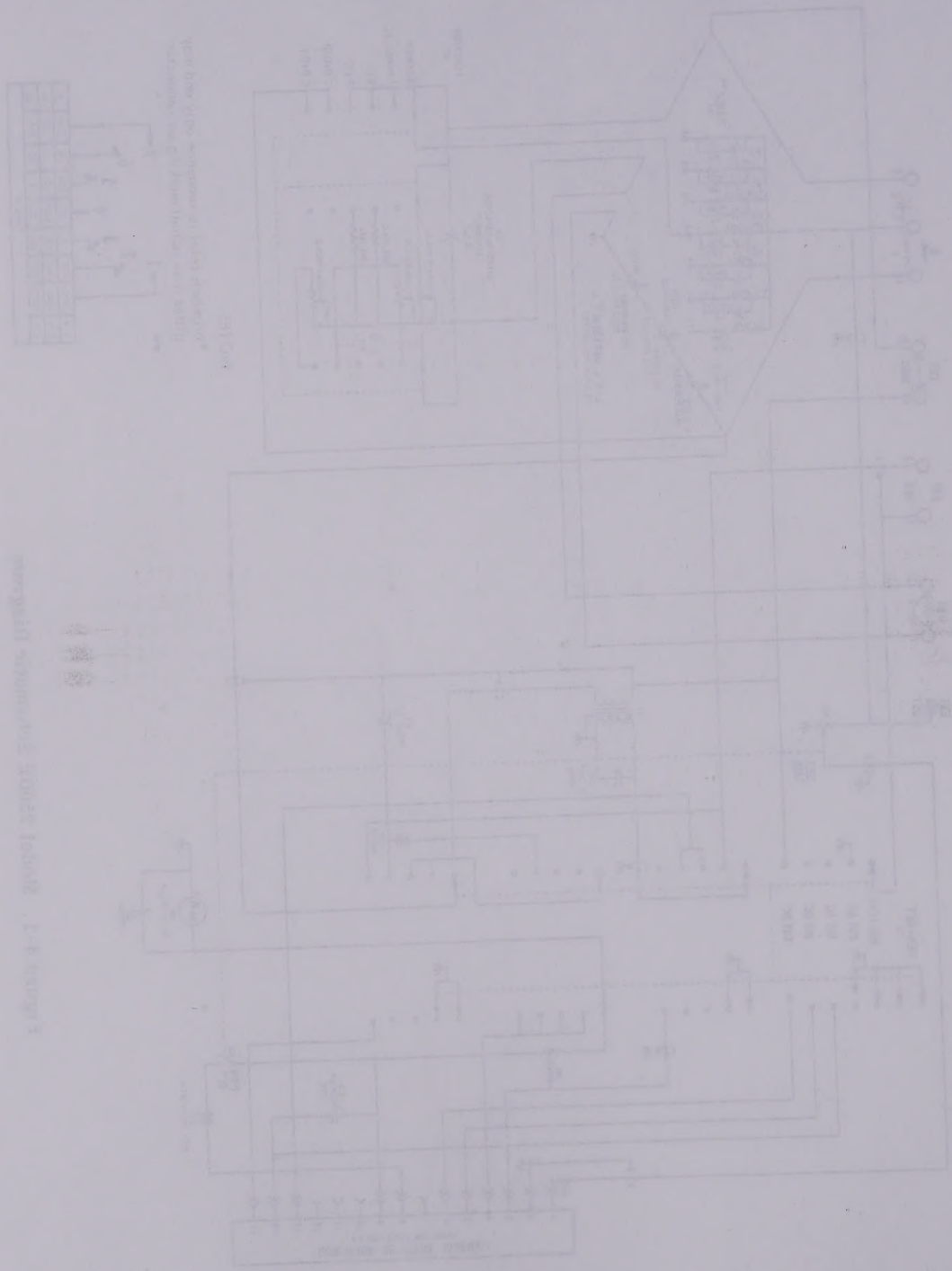


Figure 4-1. Model 250DE Schematic Diagram



GENERATOR-DETECTOR ASSEMBLY, A2

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C2	Capacitor, 0.1 μF	313-06470
C3-C4, C6-C7, C11-C12, C14, C18, C26, C31	Capacitor, 39 μF	314-06473
C5, C22	Capacitor, 0.01 μF	313-12260
C13, C16-C17	Capacitor, 180 μF	314-06474
C15	Capacitor, 2.2 μF	313-13283
C23-C25, C29	Capacitor, 1 μF	314-06472
C27	Capacitor, 1000 pF	313-07094
CR1-CR2	Diode, 1N276	321-13287
F1	Assembly, Input Filter	343-13292
F2	Assembly, Detector Network	343-13291
F3	Assembly, Generator Network	343-13290
Q1-Q8, Q10-Q11	Transistor, 2N2925	321-06467
Q9, Q12	Transistor, 2N1307	321-13243
R5, R8	Resistor, 8.2 kΩ, ¼ W, ±10%	307-13932
R6, R29, R32	Resistor, 10 kΩ, ¼ W, ±10%	307-13933
R7, R9, R36	Resistor, 3.3 kΩ, ¼ W, ±10%	307-13926
R10	Resistor, 5.6 kΩ	307-13928
R11, R33	Resistor, 100 kΩ, ¼ W, ±10%	307-13945
R12	Resistor, 390 Ω, ¼ W, ±10%	307-13914
R13	Resistor, 1.5 MΩ, ¼ W	307-13961
R14, R16	Resistor, 1.2 kΩ, ¼ W, ±10%	307-13921
R17, R20	Resistor, 1 kΩ, ¼ W, ±10%	307-13920
R18, R28	Resistor, 27 kΩ, ¼ W, ±10%	307-13938
R22, R26	Resistor, 22 kΩ, ¼ W, ±10%	307-13937
R27	Resistor, 56 kΩ, ¼ W, ±10%	307-13943
R30	Resistor, 4.7 kΩ, ¼ W, ±10%	307-13927

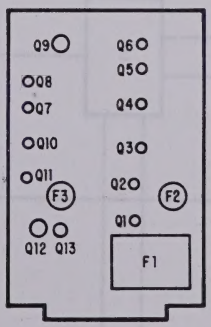
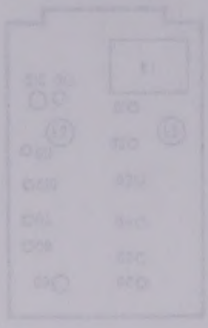
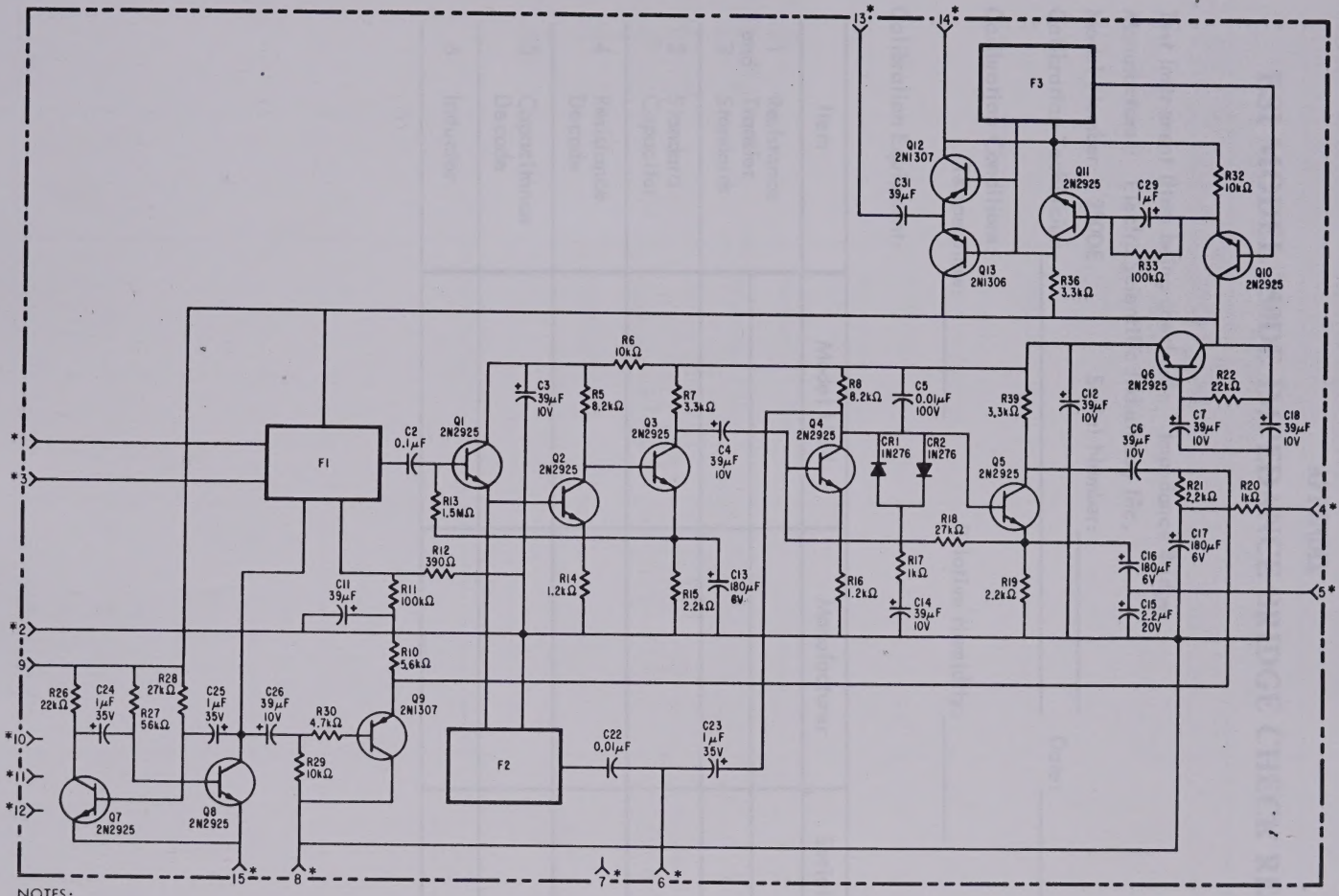


Figure 4-2. Location of Components on Circuit Board Assembly 13216



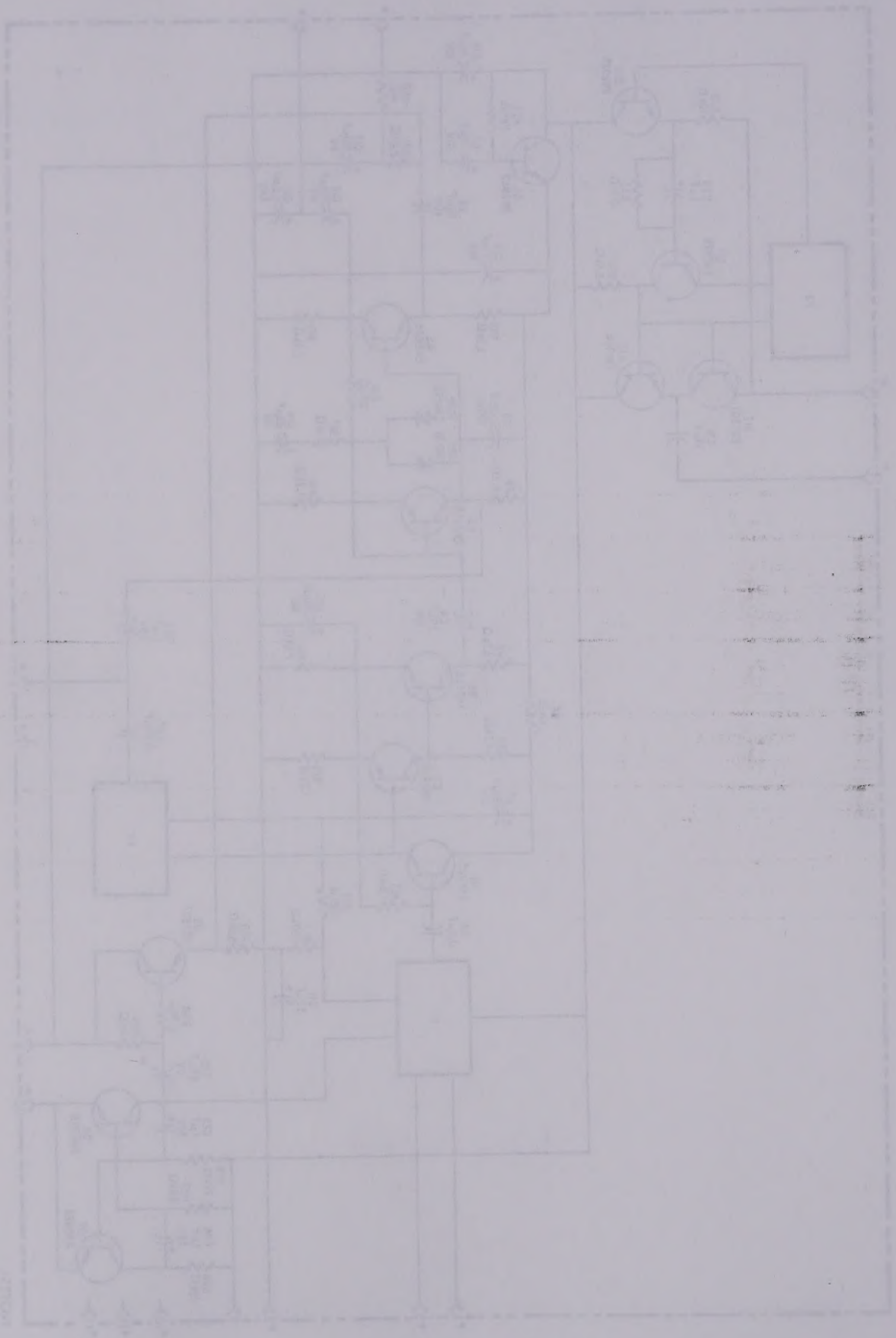


NOTES:

* Numbers refer to sequence only and may differ from actual marking on connector

Resistors 10% 1/4 watt unless noted

Figure 4-3. Generator-Detector Assembly A2 Schematic Diagram



APPENDIX

ESI MODEL 250DE IMPEDANCE BRIDGE CHECK RECORD

Test Instrument (Item being checked): Impedance Bridge

Manufacturer: Electro Scientific Industries, Inc.

Model Number: 250DE Serial Number: _____

Calibration Technician: _____ Date: _____

Calibration Conditions:

Temperature: _____ Relative Humidtty: _____

Calibration Equipment:

Item	Model Used	Manufacturer	Serial No.
1 and 2 Resistance Transfer Standards			
3 Standard Capacitor			
4 Resistance Decade			
5 Capacitance Decade			
6 Inductor			

APPENDIX

ESI MODEL 250DE IMPEDANCE BRIDGE CHECK RECORD

Test Instrument Item being checked: Impedance Bridge

Manufacturer: Electro Scientific Industries, Inc.

Model Number: 250DE Serial Number: _____

Calibration Technician: _____ Date: _____

Calibration conditions:

Temperature: _____ Relative Humidity: _____

Calibration Equipment:

Item	Model Desig.	Manufacturer	Serial No.
1 Resistance and Tolerance			
2 Standards			
3 Loaded Capacitor			
4 Reference Decade			
5 Capacitance Decade			
6 Inductor			

ESI MODEL 250DE CALIBRATION RECORD

Section (Test)	Step	Parameter	Recorded Value	Within Tolerance? ( )
0.1-Ohm	7	Zero Resistance	_____	
0.1-Ohm	8	Measured 1Ω	_____	
0.1-Ohm	9	Measured value less zero resistance	_____	_____
1-Ohm	3	Measured 10Ω	_____	
1-Ohm	4	Measured less zero resistance	_____	_____
10-Ohm	3	Measured 100Ω	_____	
10-Ohm	4	Measured value less zero resistance	_____	_____
100-Ohm	4	Measured 1kΩ	_____	_____
1-Kilohm	3	Measured 10kΩ	_____	_____
10-Kilohm	3	Measured 100kΩ	_____	_____
100-Kilohm	2	Measured 100kΩ	_____	_____
R x 10	3	Measured 100kΩ	_____	_____
First Dial	4	Dial Settings		

First Dial	All Dials	
0	_____	_____
1	_____	_____
2	_____	_____
3	_____	_____
4	_____	_____
5	_____	_____
6	_____	_____
7	_____	_____
8	_____	_____
9	_____	_____
10	_____	_____
11	_____	_____

Section (Test)	Step	Parameter	Recorded Value	Within Tolerance ?( )
Second Dial	5	Dial Settings		
		Second Dial	All Dials	
		0	_____	_____
		1	_____	_____
		2	_____	_____
		3	_____	_____
		4	_____	_____
		5	_____	_____
		6	_____	_____
		7	_____	_____
		8	_____	_____
		9	_____	_____
		X	_____	_____
Third Dial	5	Dial Setting		
		Third Dial	Third Dial	
		10	_____	_____
		20	_____	_____
		30	_____	_____
		40	_____	_____
		50	_____	_____
		60	_____	_____
		70	_____	_____
		80	_____	_____
		90	_____	_____
		100	_____	_____
3.2.7	5	Capacitance Check	_____	_____

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The reference standards of measurement of Electro Scientific Industries, Inc., are compared with the U.S. National Standards through frequent tests by the U.S. National Bureau of Standards. The ESI working standards and testing apparatus used are calibrated against the reference standards in a rigorously maintained program of measurement control.

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Final calibration of this instrument was performed with reference to the mean values of the ESI reference standards or to ratio devices that were verified at the time and place of use.

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2. Two years on components and instruments utilizing exclusively passive circuitry.

During the in-warranty periods, we will service or, at our option, replace, at the factory, any device that fails in normal use to meet its published specifications. Batteries, tubes, and relays that have given normal service are excepted. Special systems will have warranty periods as listed in their quotation.

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